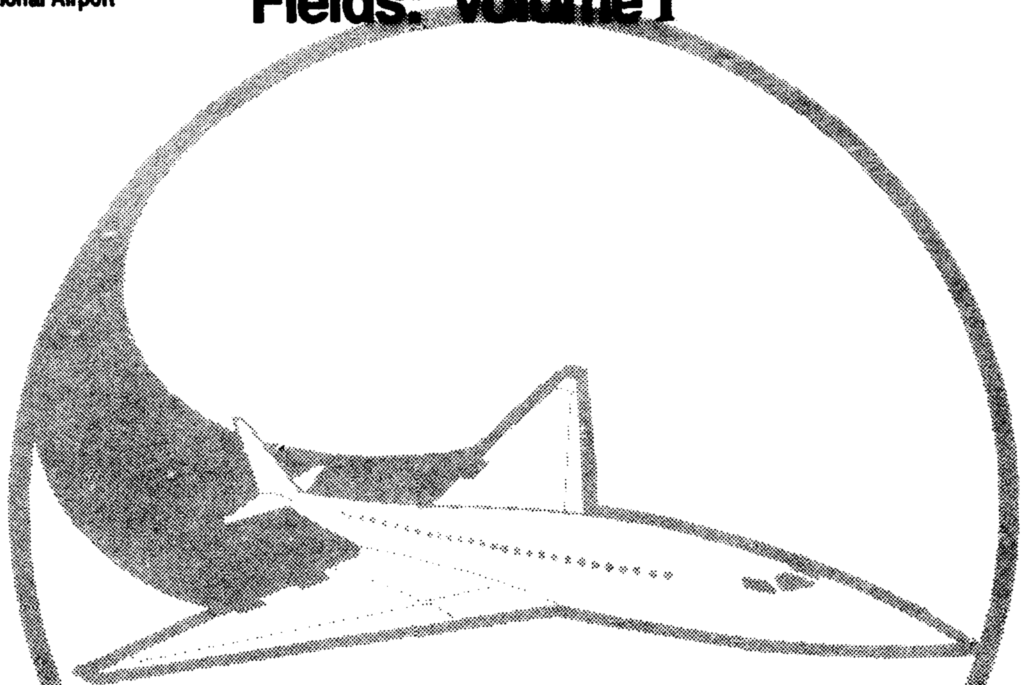
AD-A274 571

DOT/FAA/CT-93/5-I

FAA Technical Center
Atlantic City International Airport
N.J. 08405

S-76 High Intensity Radiated Fields: Volume I



October 1993

Final Report

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

This document is disseminated under the sponsorship of the U. S. Department of Transportation in the interest of information exchange. The United States Government assumes no liability for the contents or use thereof.

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the objective of this report.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/CT-93/5, I*		

4. Title and Subtitle

S-76 HIGH INTENSITY RADIATED FIELDS: VOLUME I

5. Report Date

October 1993

6. Performing Organization Code

7. Author(s)

Jerry Blair

8. Performing Organization Report No.

9. Performing Organization Name and Address

SCIENTECH, Inc.
1690 International Way
Idaho Falls, Idaho 83402

10. Work Unit No. (TRAIS)

11. Contract or Grant No.

12. Sponsoring Agency Name and Address

U.S. Department of Transportation
Federal Aviation Administration
Technical Center
Atlantic City International Airport, NJ 08405

13. Type of Report and Period Covered

Final Report

14. Sponsoring Agency Code

ACD-230

15. Supplementary Notes

FAA Project Manager: Michael Glynn * Volume I of III

16. Abstract

The Federal Aviation Administration (FAA) Technical Center sponsored a series of High Intensity Radiated Fields (HIRF) test on a Sikorsky S-76 rotorcraft. The project was conducted to evaluate the practically of performing aircraft level HIRF tests, determine the effects of HIRF on a specific rotrocraft with the potential to obtain information on rotorcraft in general, and evaluate the effects of exposure to "real world" HIRF emitters.

HIRF ground and flight tests were conducted to achieve the objective of the project. Site calibration (SCAL) measurements were made in the test area to determine the levels at which the S-76 would be irradiated when placed in the test area. Ground tests consisted of Low Level Swept Coupling (LLSC) and Low Level Swept Fields (LLSF) tests. The flight tests were flown directly into the main beam of a variety of pulsed and continuous wave (CW) transmitters including the Over the Horizon Back Scatter (OTHB), PAVE PAWS, ASR-9, FPS-65, and FPS-16 radars. Results of the S-76 tests added credibility to the existence of HIRF as a flight safety hazard. In the evaluation of the emitters, the flight tests showed repeatable instances where exposure resulted in instrumentation disruptions. It should however be noted that all the observed disruptions were of a non-critical nature.

17. Key Words

HIRF
Electromagnetic Fields
LLSC
Helicopter

18. Distribution Statement

Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	88	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGMENTS

Since its start in March of 1991, many people have contributed to the success of the S-76 Rotorcraft High Intensity Radiated Fields (HIRF) Test Project. While all of the people involved in the S-76 HIRF Test Project deserve special thanks for their dedication and hard work, they are too numerous to name individually. It is appropriate and warranted to specifically recognize and thank some of the key contributors.

The support provided by the Federal Aviation Administration Technical Center (FAATC) Modification Shop (Mod Shop) personnel ensuring the S-76 was in place and ready for testing significantly contributed to completion of the ground tests in a timely manner. When we needed to fabricate a replacement antenna, the Mod Shop personnel came through with tools and materials necessary to keep the project moving.

The Flight Operations engineering staff, specifically Armando Getano, spent many hours designing special equipment mounts necessary to maintain safety standards during the flight tests.

The S-76 pilot, Mark Ehrhart, made it possible to perform the entire flight test portion of the project. Mark's eagerness, interest, and willingness to support a dynamic schedule contributed to the success of the flight tests.

The Rome Laboratory Radar Test Range personnel also deserve special thanks. In particular, John Mecca adapted to an extremely dynamic schedule and was understanding of delays due to equipment outages and poor weather.

TABLE OF CONTENTS
Volume I

TABLE OF CONTENTS
Volume I
(CONTINUED)

TABLE OF CONTENTS
Volume II

TABLE OF CONTENTS
VOLUME III

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS and ABBREVIATIONS

	A
A	Amperes
AF	Antenna factor
ASR	Air Surveillance Radar
	C
CRT	Cathode Ray Tube
CW	Continuous Wave
	D
dB	Decibel
dBm	Decibels Referenced to One Milliwatt
dBuA	Decibels Referenced to One Microampere
dBuV/m	Decibels Referenced to One Microvolt per Meter
DC	Directional Coupler
	E
EFAVdBm	E-Field Average in dBm
EFAVdBuV/m	E-Field Average in dBuV/m
EFAVdBV/m	E-Field Average in dBV/m
EFPKdBV/m	E-Field Peak in dBV/m
EFdBm	E-Field in dBm
EFV/m	E-Field in V/m
E-Field	Electromagnetic Field
EMI	Electromagnetic Interference
ER	Extrapolation Ratio
ERP	Effective Radiated Power
	F
FAA	Federal Aviation Administration
FAATC	Federal Aviation Administration Technical Center
	G
GHz	Gigahertz
GPIB	General Purpose Interface Buss
GW	Gigawatt
	H
HF	High Frequency
HHC	High Hover Calibration
HIRF	High Intensity Radiated Fields
Hz	Hertz
ICOM	Manufacturer's Nomenclature for AH-7000 25-1300 MHz Discone Antenna
	I
IEEE	Institute of Electrical and Electronic Engineers
IL	Insertion Loss

LIST OF ACRONYMS and ABBREVIATIONS
(Continued)

	K	
kHz	Kilohertz	
kW	Kilowatt	
	L	
LLSC	Low-Level Swept Coupling	
LLSF	Low Level Swept Fields	
	M	
MHz	Megahertz	
MTCB	Mobile Transmit-Control Building	
MW	Megawatt	
	N	
NPRM	Notice of Proposed Rule Making	
	O	
OTHB	Over the Horizon - Back Scatter	
	P	
PVC	Polyvinyl-Chloride	
	R	
RF	Radio Frequency	
RSBW	Resolution Bandwidth	
	S	
S-76	Sikorsky 76 Helicopter	
SAE-AE4R	Society of Automotive Engineers AE4R Committee	
SCAL	Site Calibration	
SCALdBm	SCAL in dBm	
SCALdBuV/m	SCAL in dBuV/m	
SCALV/m	SCAL in V/m	
SCIENTECH	SCIENTECH, Inc.	
SNR	Signal-to-Noise Ratio	
	T	
TC	Technical Center	
	U	
USAF	United States Air Force	
	V	
V/m	Volts per meter	
VFR	Visual Flight Rules	

EXECUTIVE SUMMARY

The Federal Aviation Administration (FAA), in support of its on-going efforts to evaluate and define requirements for aircraft/systems High Intensity Radiated Fields (HIRF) certification, has sponsored a variety of HIRF related research projects. One project, the topic of this report, consisted of conducting a series of HIRF related tests on a Sikorsky S-76 rotorcraft. This Executive Summary provides a survey of the purpose, approach, and results of the S-76 HIRF Test Project.

PURPOSE

The S-76 HIRF Test Project was conducted to evaluate the practicality of performing aircraft level HIRF tests, determine the effects of HIRF on a specific rotorcraft with the potential to obtain information on rotorcraft in general, and evaluate the effects of exposure to "real world" HIRF emitters.

APPROACH

HIRF ground and flight tests were conducted to achieve the objectives of the S-76 Test Project.

The ground test portion of the project consisted of Low Level Swept Coupling (LLSC) and Low Level Swept Fields (LLSF) tests. The LLSC tests were performed to measure and evaluate the amount of current induced on selected internal cable bundles while exposing the S-76 to low level HIRF. Similarly, the LLSF tests were performed to measure and evaluate the resulting onboard electromagnetic field (E-Field) levels during the low level HIRF exposure. Both the LLSC and LLSF tests were conducted by placing E-Field and current monitoring sensors in various onboard locations while irradiating the S-76 with low level (from 0.001 to 8.1 Volts per meter (V/m)) E-fields over a frequency range of 10 kilohertz (kHz) to 18 gigahertz (GHz).

Prior to the LLSC and LLSF tests, site calibration (SCAL) measurements were made without the S-76 located in the test area to determine the levels at which the S-76 would be irradiated when placed in the test area.

The flight test portion of the project consisted of monitoring the resulting onboard E-Field levels while exposing the S-76 to HIRF generated by "real world" emitters. During these tests, the S-76 was flown directly into main beam of a variety of pulsed and continuous wave (CW) transmitters including the Over the Horizon Back Scatter (OTHB), PAVE PAWS, ASR-9, FPS-65, and FPS-16 radars. To record any possible disruptions to the flight instruments, a video camera was installed and recorded the operation of the co-pilot display unit.

RESULTS

The objectives of the S-76 HIRF Test Project included:

- evaluation of HIRF test practicality
- evaluation of HIRF effects on rotorcraft
- evaluation of the HIRF threat environment

The S-76 HIRF Test Project identified many technical constraints which will continue to impact the ability to conduct technologically ideal HIRF certification tests. The project provided insight into the potentially high costs associated with performing aircraft level HIRF certification tests implying the need to continue exploring alternate HIRF test methodologies.

The ground tests indicated the S-76, and perhaps most rotorcraft, are more susceptible to the effects of HIRF than previously tested commercial aircraft. This conclusion is based on the test results which indicated that the induced cable current levels, when extrapolated to full threat, were much higher than proposed test levels identified in DO-160C.

Results of the S-76 tests added credibility to the existence of HIRF as a flight safety hazard. In the evaluation of the "real world" emitters, the flight tests showed repeatable instances where exposure to "real world" HIRF emitters resulted in instrumentation disruptions. It should however be noted that all of the observed disruptions were of a non-critical nature.

1. BACKGROUND

Over the past 20 years, advances in communications and radar technologies have created an environment in which aircraft during operations (takeoff, landing, and flight operations) are exposed to unacceptable levels of High Intensity Radiated Fields (HIRF). While in flight, exposure to HIRF can cause disruptions to flight-critical and essential systems, significantly impacting flight safety. The likelihood of disruptions occurring has steadily increased as aircraft manufacturers have been replacing mechanical critical and essential systems with modern, but more HIRF-susceptible, computer-driven electronic systems. Susceptibility of modern aircraft to the effects of HIRF is further increased by the use of non reflective composite materials in the fabrication of wing, tail, and fuselage structures.

To address the potential impacts of HIRF on flight safety, the Federal Aviation Administration Technical Center (FAATC), with assistance from the Society of Automotive Engineers (SAE), the AE4R Committee has been working to define the current and anticipated HIRF environment to establish recommended approaches to verify aircraft are not susceptible to the effects of HIRF.
Upon completion of the FAA and SAE-AE4R Committee's efforts, the FAA will prepare, and release for comment, a Notice of Proposed Rule Making (NPRM) outlining HIRF certification requirements.

When implemented, the certification requirements defined in the NPRM will require that aircraft manufacturers address HIRF issues in their designs and verify immunity to the effects of HIRF. Since such requirements will impact the overall aircraft manufacturing and certification process, the FAATC has sponsored a variety of research projects to investigate the effects of HIRF and to evaluate the practicality of performing HIRF certification tests.

One of the FAATC's research projects, the topic of this report, involved conducting a series of HIRF related tests on a Sikorsky S-76 rotorcraft.

2. OBJECTIVES

The S-76 HIRF test was conducted to satisfy three major objectives:

- evaluate HIRF testing practicality
- evaluate the HIRF effect on rotorcraft
- evaluate the threat environment

2.1 HIRF Test Practicality

The first objective of the S-76 HIRF test was to evaluate whether HIRF testing, conducted in accordance with the "ARD50042-Users' Manual for AC-XX-XX, "High Intensity Radiated Fields (HIRF)" 2 April 1993, and EUROCAE WG-33, Subgroups 2 and 3 Users' Guide for AC No. 20-XX, Protection of Aircraft Electrical and Electronic Systems Against the Effects of External Radio Frequency Environment," 5 June 1990, could be performed in a practical, effective, and efficient manner.

2.2 HIRF Effects on Rotorcraft

The second objective of the HIRF test was to identify the vulnerabilities of the S-76 which, through analysis, could provide insight into the susceptibility of rotorcraft in general. While much attention has been given to addressing the impact of HIRF on fixed-wing aircraft, little or no emphasis has been placed on HIRF effects on rotorcraft. When evaluating the potential vulnerabilities of rotorcraft, the increased number of apertures and outer areas composed of composite materials lead to the suspicion that such aircraft are inherently more susceptible to the effects of HIRF. While not intending to imply that the S-76 is representative of all rotorcraft, it appeared to have design aspects that address both best and worst case susceptibilities to HIRF. Additionally, the FAA's S-76 was uniquely equipped with an Electronic Flight Instrumentation System (EFIS) allowing the a evaluation of flight instrumentation component common to fixed wing aircraft and rotorcraft.

2.3 HIRF Threat Environment Evaluation

The third objective of the S-76 HIRF test was to evaluate the effects of "real world" HIRF emitters on the S-76 while in flight. Much effort has been expended in identifying the existing HIRF emitters, while little actual in-flight testing has been performed.

3. SCOPE

The S-76 HIRF test project consisted of two phases. The first phase, consisting of ground tests, included Site Calibration (SCAL), Low Level Swept Coupling (LLSC), and Low Level Swept Fields (LLSF) performed at the FAATC, Atlantic City International Airport, NJ. The second phase included a series of flight tests where the S-76 was exposed to "real world" emitters while the onboard electromagnetic field (E-Field) levels were monitored and recorded.

4. S-76 GROUND TESTS

The ground tests were performed to accomplish two objectives. First, the SCAL, LLSC and LLSF tests provided estimates of the S-76's ability to attenuate E-Fields over the frequency range of 10 kHz to 18 GHz. Second, the tests provided a means to evaluate the feasibility and practicality of conducting HIRF tests.

During all portions of the ground tests, measurements were made using a test system comprised of a receive node and a combined transmit and control node, depicted in Figures 4-1 and 4-4. The received signals were transmitted from spectrum analyzers in the receive node to a central control processor in the transmit and control node via a fiber optic link. In both nodes, the equipment was controlled using an Institute of Electrical and Electronic Engineers (IEEE) 488 General Purpose Interface Buss (GPIB).

The following sections provide details of the various tests, discuss the technical approach, describe the data analysis techniques, and provide summaries of the findings associated with the S-76 HIRF ground tests. The complete HIRF data from which the summaries were prepared are provided in Volume II of this report.

Figure 4-1. Test System Receive Node Photograph

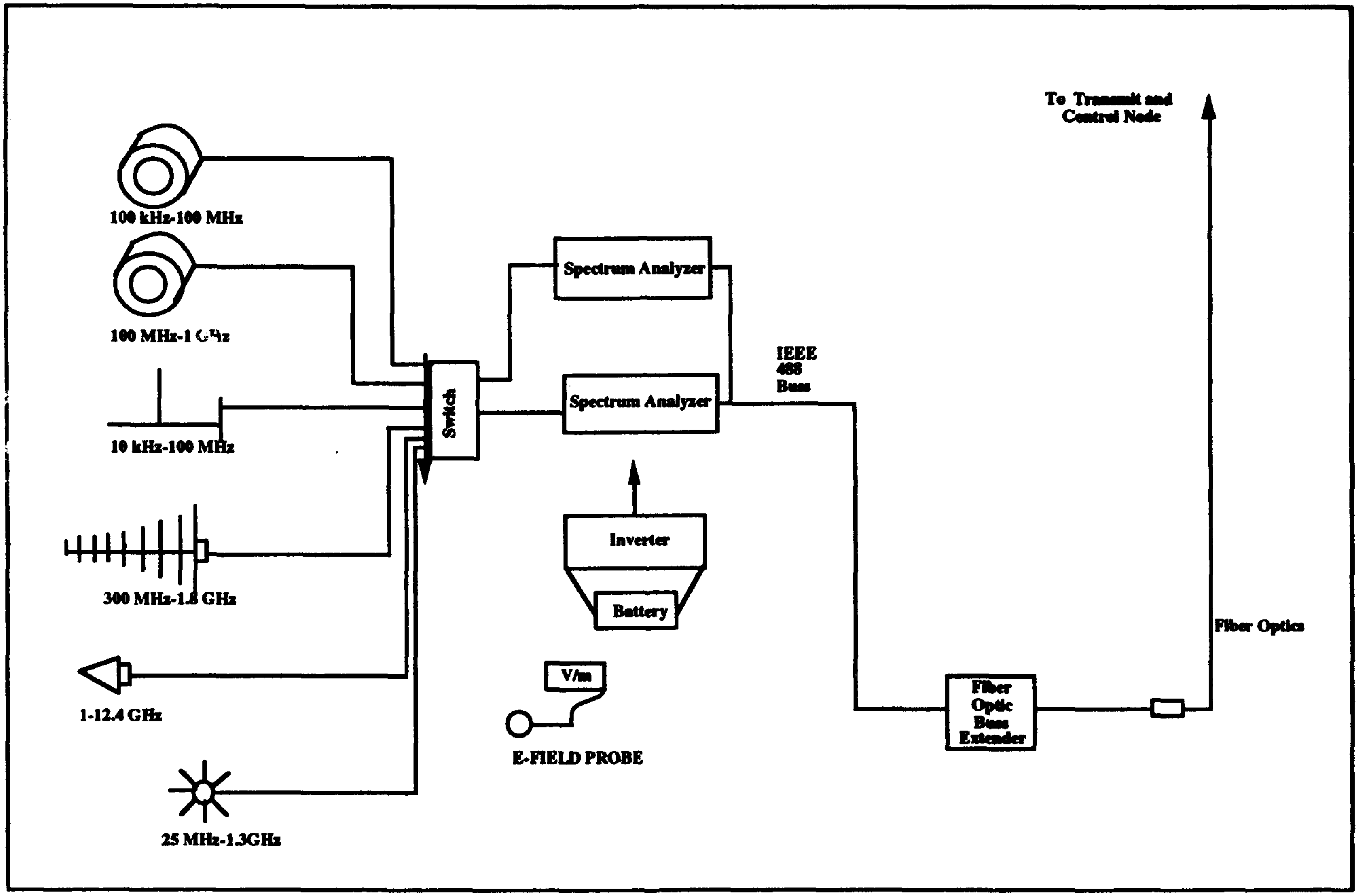
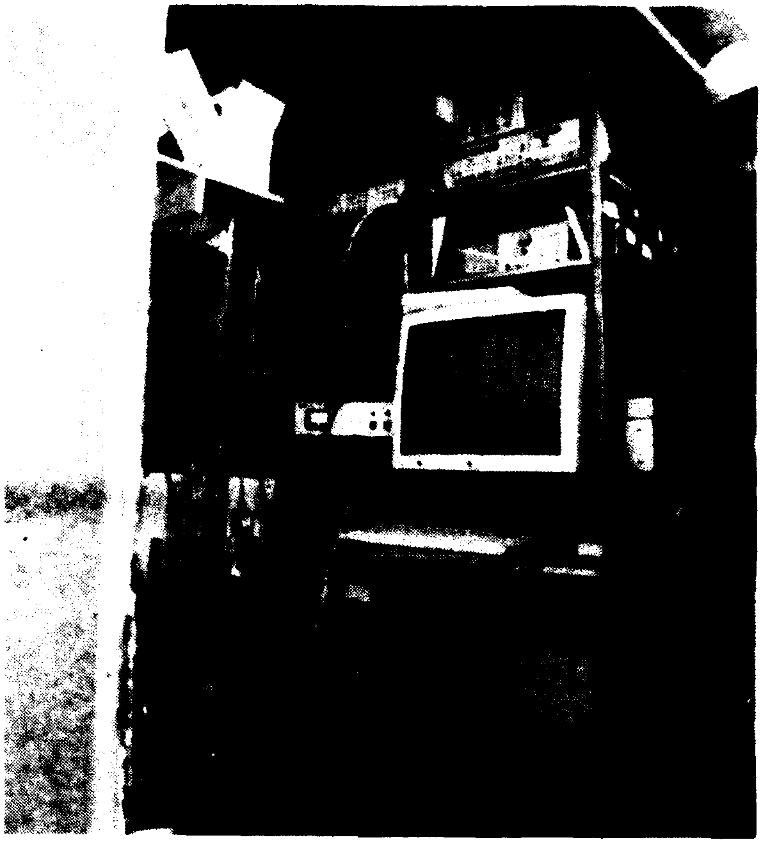


Figure 4-2. Test system Receive Node



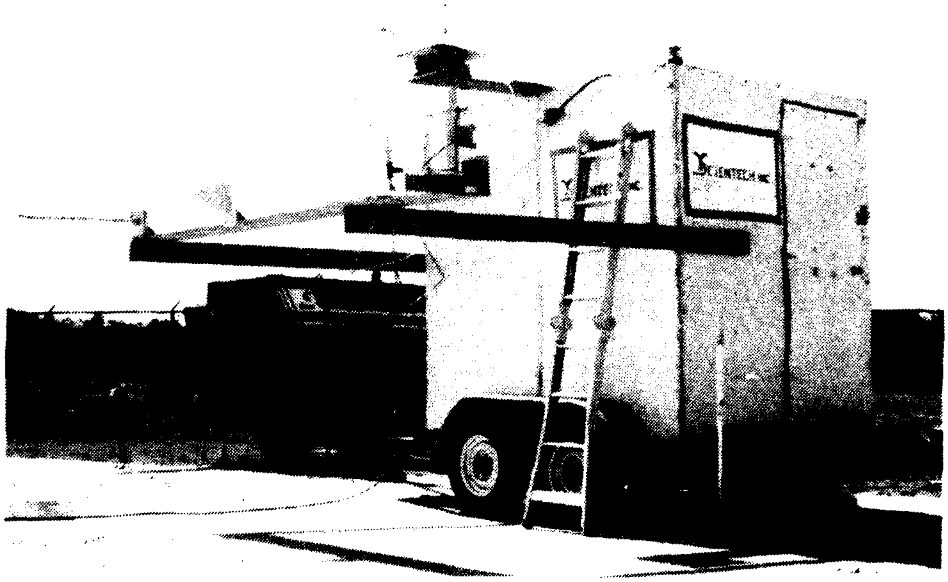


Figure 4-3 Test System Transmit and Control Node Photographs

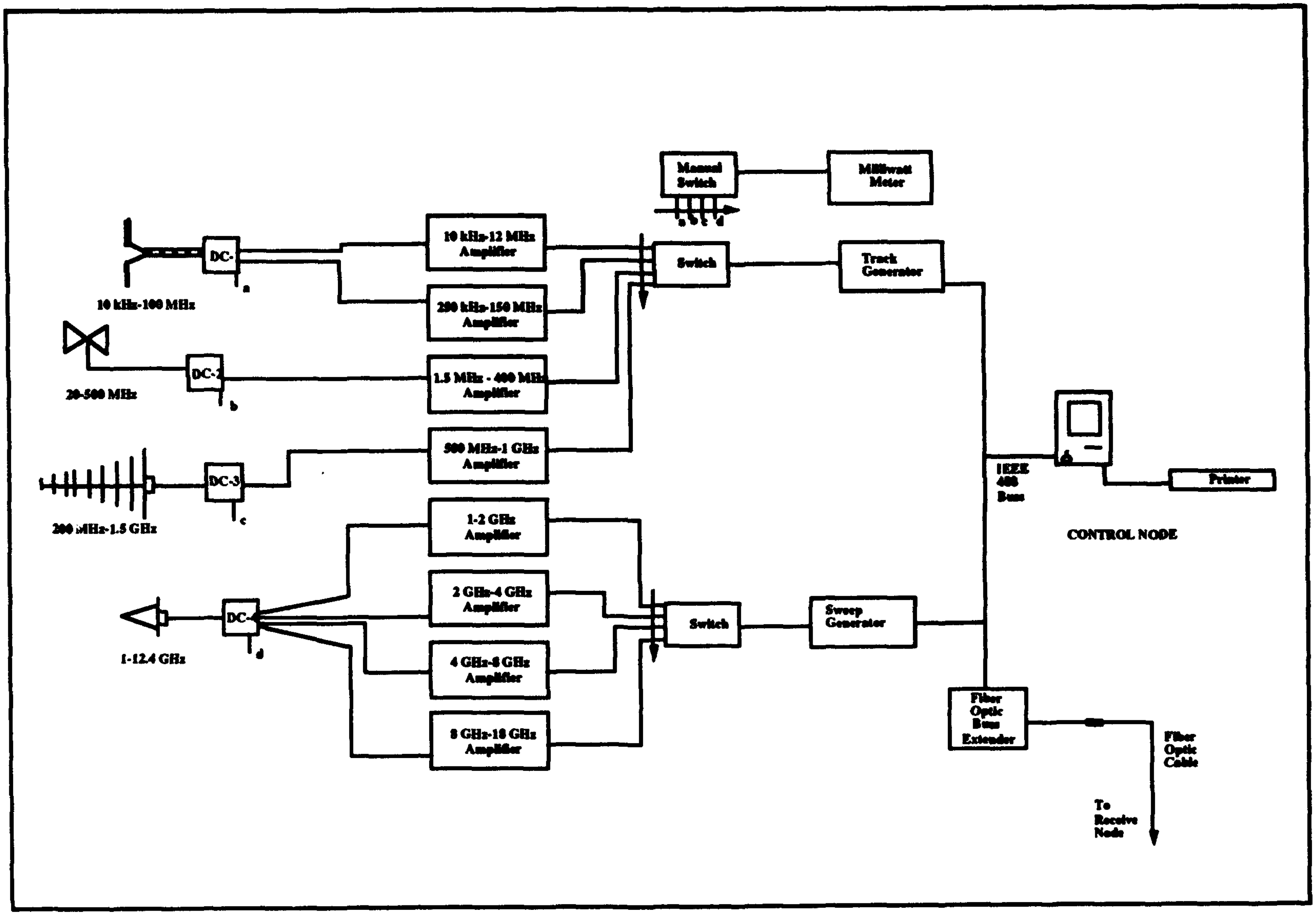


Figure 4-4. Test System Transmit and Control Node

4.1 Site Calibration

The SCAL portion of the HIRF ground tests was performed prior to placement of the S-76 in the test area. The purpose of the SCAL was to determine the background noise and E-Field levels that would be incident on the helicopter during the LLSC and LLSF tests.

4.1.1 SCAL Technical Approach

SCAL consisted of two parts: transmitted E-Field and background noise measurements. Transmitted E-Field measurements were performed by irradiating the test area over the frequency range of 10 kHz to 18 GHz while measuring and recording the resulting E-Field levels. This portion was performed to verify the levels at which the S-76 would be irradiated when placed in the test area. To achieve optimum E-Field levels, variables such as amplifier output power and the distance between the transmit and receive antennae were modified to achieve the maximum signal to noise ratios and E-Field levels. Figures 4-5 and 4-6 shows the SCAL configuration used during this portion of the test. During the second part of SCAL, background measurements were performed to determine if nearby emitters were broadcasting in the frequency band of concern.

During SCAL, current probes were placed on a wire loop in the test area. This was done to verify the ability to measure induced cable current over the range of 10 kHz to 1 GHz, and to verify that no significant noise was injected into the system by the current monitor probes. Approximately half way through the LLSF and LLSC tests, due to a test system configuration change necessitated by wind damage to a transmit antenna, a second SCAL was performed. Results of the second SCAL were used to process all data acquired after the configuration change ensuring data validity. A detailed discussion of the configuration change is provided in Section 6.4.

The SCAL E-Field data were used in conjunction with the full-threat levels defined in the "ARD50042- Users' Manual for AC-XX-XX, "High Intensity Radiated Fields (HIRF)" 2 April 1993, to determine a full-threat extrapolation ratio (ER) to be used during the data processing and analysis.

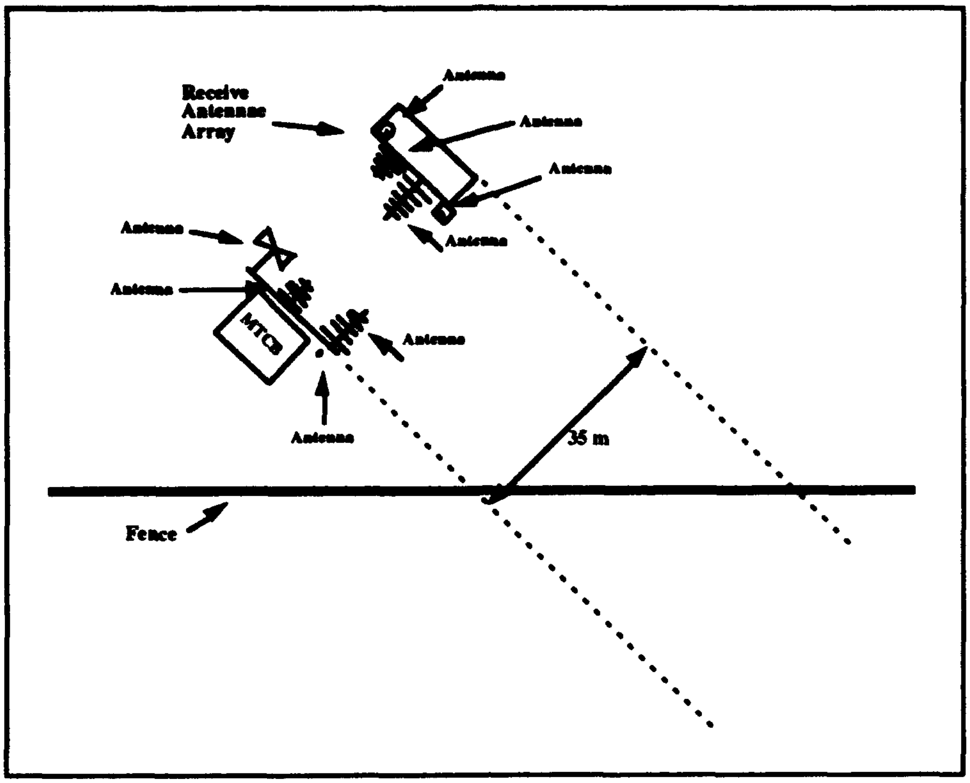


Figure 4-5. SCAL Configuration

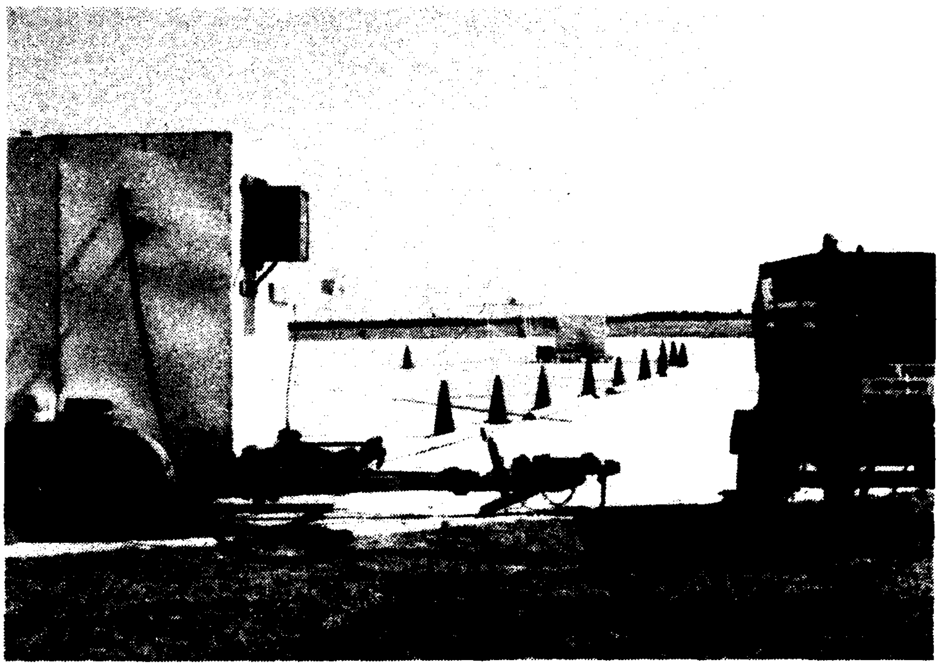


Figure 4-6. SCAL Configuration Photograph

While actual LLSC and LLSF measurements were performed with two transmit and four receive configurations, SCAL was performed with one transmit and one receive location configuration as indicated in Figure 4-5. The SCAL reduction in transmit and receive configurations was justified due to the close proximity of the onboard receive configurations and consideration that the measured E-Field levels in V/m are inversely proportional to the distance between the aircraft and transmit antennae.

4.1.2 SCAL Data Processing

The acquired SCAL data were processed to correct for system and cable losses, to apply the manufacturer's antenna factors, and to convert the results to engineering units (V/m). The following algorithms were applied in each step of the SCAL data processing:

- $SCAL_{dBuV/m} = SCAL_{dBm} + AF + IL$
  where:
  - $SCAL_{dBm}$ is the raw data acquired from the receive spectrum analyzer.
  - AF is the manufacturer supplied antenna factor.
  - IL is the receive system equipment and cable loss.
  - $SCAL_{dBuV/m}$ is $SCAL_{dBm}$ corrected for losses and antenna factors and converted from raw data to E-Field quantity.

- $SCAL_{V/m} = 10^{-6}[Log^{-1}(SCAL_{dBuV/m}/20)]$
  where:
  - $SCAL_{V/m}$ is the corrected data converted to V/m.

4.1.3 Summary of Results

As previously mentioned, the SCAL data were used during the process of extrapolating the LLSC and LLSF data to full threat and to calculate the aircraft attenuation levels. Therefore, it was important to achieve the best possible signal to noise ratio (SNR) possible during the SCAL measurements. Ideally, a minimum of 10 dB SNR was desirable; however, equipment limitations did not accommodate this desire. Figures 4-7 and 4-8 provide a summary of the SNR values for both sets of the SCAL measurements. The detailed data from which the summary was derived is provided in Volume II.

In addition to a desired SNR, E-Field levels, during all aspects of aircraft level testing, would ideally be 1 V/m. As with SNR, equipment limitations, such as limited amplifier input and output levels, did not make this goal achievable without considerable expense. Further, it was desirable, during low level tests, to irradiate the aircraft with a constant E-Field level throughout each frequency band. Again, equipment limitations and time constraints made this desire unachievable.

While not ideal, the incident E-Field levels measured ranged from 0.0 01 to 8.1 V/m as indicated in Figures 4-9 and 4-10.

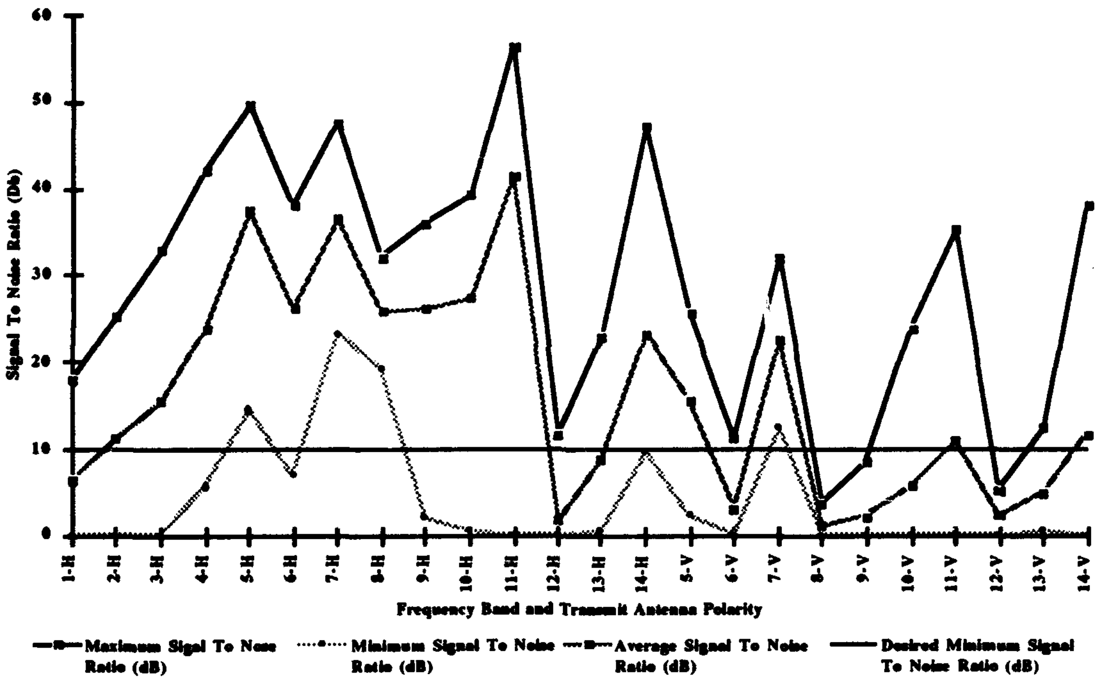


Figure 4-7. SCAL Set 1 SNR Chart

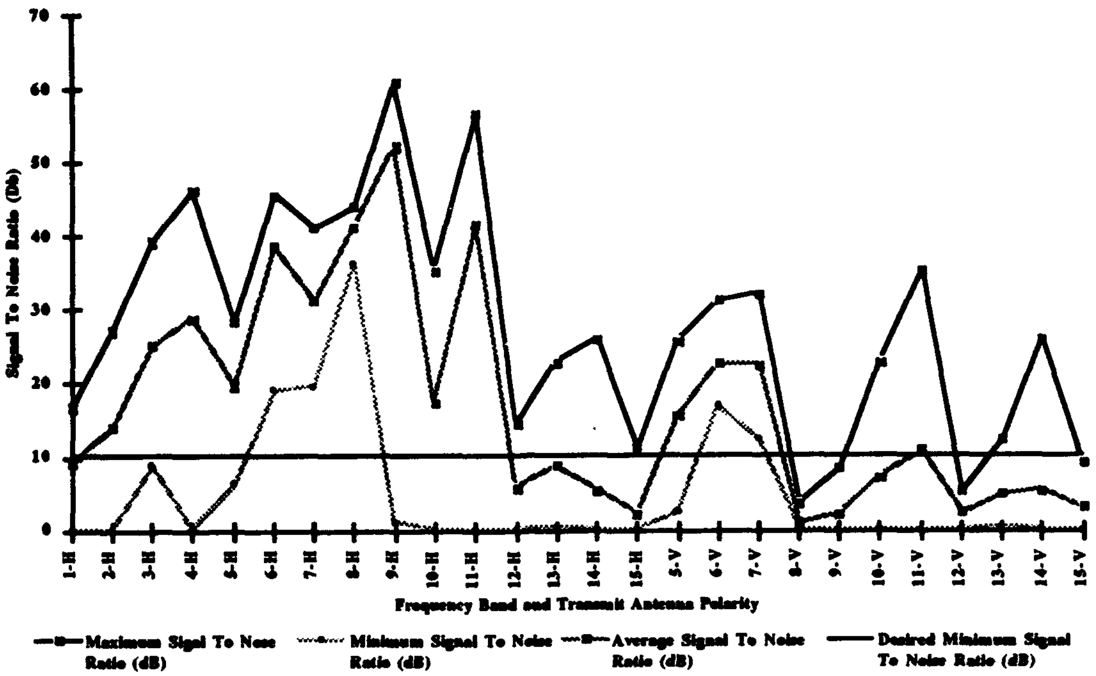


Figure 4-8. SCAL Set 2 SNR Chart

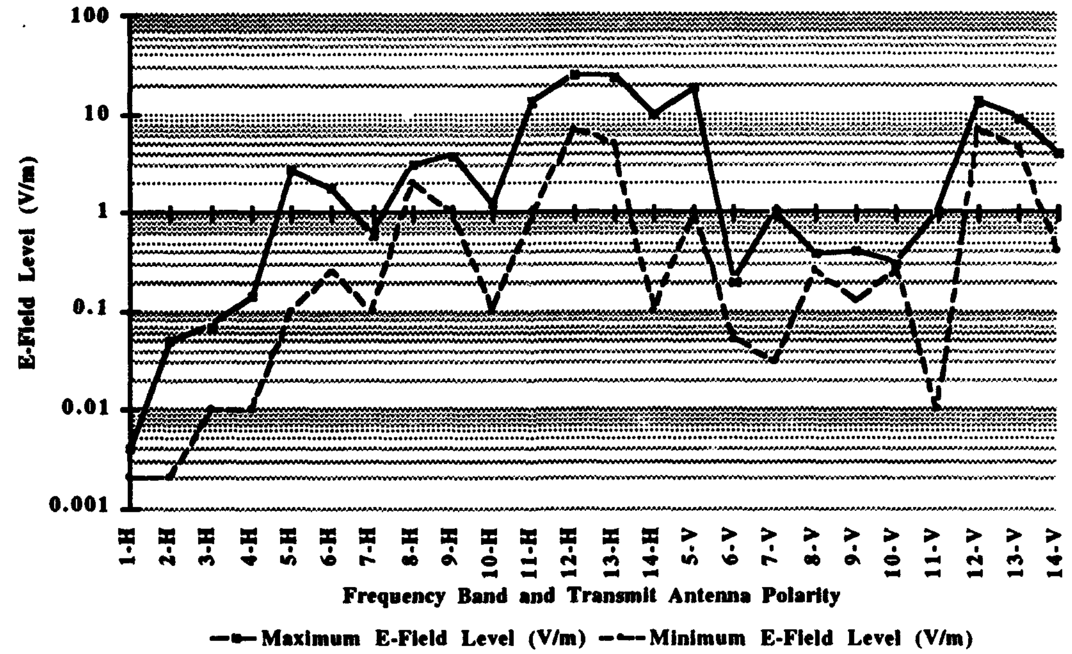


Figure 4-9. SCAL Set 1 E-Field Level Chart

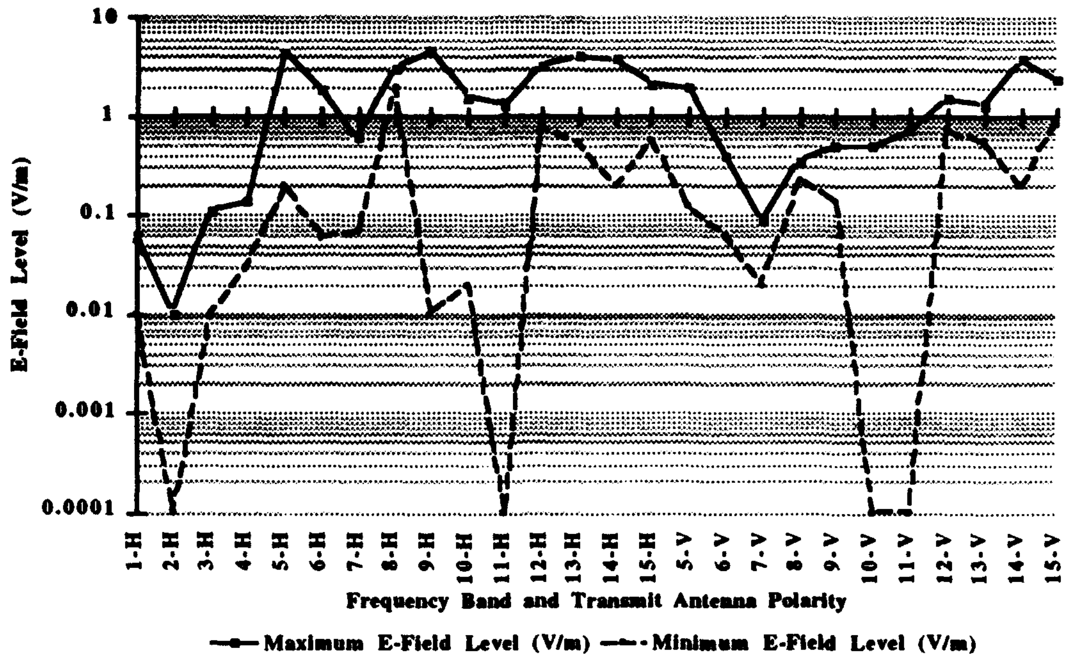


Figure 4-10. SCAL Set 2 E-Field Level Chart

4.2 Low Level Swept Fields

The LLSF tests were performed to measure the S-76's ability to attenuate E-Fields and to assist in the evaluation of current aircraft level HIRF testing methodologies. The LLSF tests were conducted in accordance with recommended procedures established in the "ARD50042-Users' Manual for AC-XX-XX, "High Intensity Radiated Fields (HIRF)" 2 April 1993.

4.2.1 LLSF Technicrl Approach

The LLSF measurements were conducted with the receive antennae positioned inside the S-76. Multiple receive antennae were necessary to cover the complete frequency range of 10 kHz to 18 GHz. During the LLSF test, the receive antennae were placed in multiple configurations as indicated in Table 4-1. Positioning of the antennae to different locations ensured measurements were made in each receive location over the entire test frequency range. Where applicable, depending on the directivity and geometry of the antennae, the S-76 was irradiated with the transmit antennae in both vertical and horizontal orientations.

Table 4-1. LLSF E-Field Sensor Locations

Configuration		E-Field Sensor Location			
Transmit Location	Rx Location Number	Monopole	ICOM	Large LPA	Small LPA
1	1	R4	R5	R3	R1
1	2	R1	R4	R5	R3
1	3	R3	R1	R4	R5
1	4	R5	R3	R1	R4
2	1	R4	R5	R3	R1
2	2	R1	R4	R5	R3
2	3	R3	R1	R4	R5
2	4	R5	R3	R1	R4

The transmit and E-Field sensor locations identified in Table 4-1 are depicted in Figure 4-11. Transmit location one (T1) corresponded to irradiation of the starboard of the aircraft, while transmit location two (T2) corresponded to a head-on irradiation of the S-76. The aircraft was rotated 90 degrees to switch from T1 to T2 instead of relocation of the actual transmit antennae array. Rotation of the aircraft allowed for a consistent E-Field path from the transmit location to the aircraft. This was particularly important as irradiation from other directions would have resulted in undesirable reflections from foreign objects (e.g., metallic fences, parked aircraft, metallic storage sheds, etc.) near the test area as depicted in Figure 4-12.

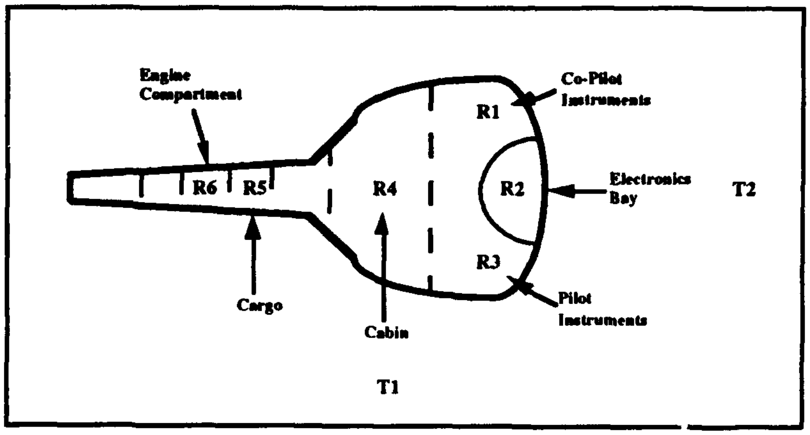


Figure 4-11 S-76 LLSF and LLSC Transmit/Receive Locations

During the first part of the LLSF and LLSC tests, the frequency range of 10 kHz to 18 GHz was divided into 14 bands. The band definitions were determined based on characteristics of the transmit and receive antennae, amplifier maximum input power levels as a function of frequency, and internal spectrum analyzer band breaks. After conducting a series of LLSC and LLSF tests, it was deemed necessary to further divide Band 14 (originally 8-18 GHz) into two bands. This change was necessitated by amplifier input power limits over the original 10 GHz wide Band 14.

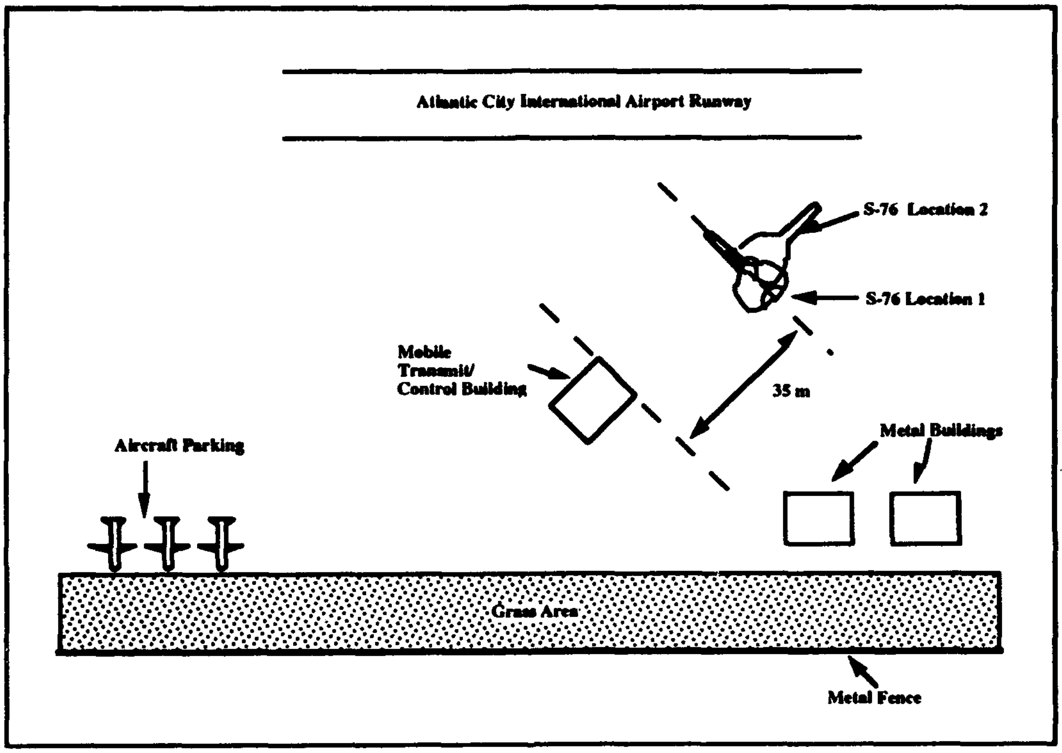


Figure 4-12. Test Area Layout

Table 4-2 identifies the modified frequency ranges for the 15 bands and the associated transmit and receive component characteristics. Specifically, band 14 originally spanned the frequency range of 8-18 GHz was broken into two bands covering the frequency ranges of 8-14 GHz and 14-18 GHz. The characteristics are based on the manufacturer data sheets and calibration data in Appendix I.

Table 4-2. Band Definitions and Characteristics

Band	Freq. - Band	Pi Amp (dBm)	Amp Gain (dB)	Cable Loss (25ft) (dB)	Pi Ant (W)	Ave. Num. Gain	ERP (W)
1	10kHz-500kHz	0.01	50.00	0.01	100.00	5.00E-08	5.00E-06
2	500kHz-2MHz	0.09	50.00	0.09	100.00	2.50E-05	2.50E-03
3	2MHz-12MHz	0.22	50.00	0.22	100.00	1.00E-03	1.00E-01
4	12MHz-150MHz	-6.50	55.00	0.65	61.00	0.67	40.80
5	50MHz-300MHz	-4.03	50.00	1.10	30.70	1.33	20.80
6	300MHz-400MHz	1.08	50.00	1.30	95.00	0.43	20.80
7	400MHz-450MHz	1.40	50.00	1.40	100.00	0.30	30.00
8	450MHz-500MHz	7.24	33.50	1.50	8.40	4.86	40.80
9	500MHz-1GHz	8.52	33.50	2.20	9.60	4.25	40.80
10	1GHz-1.8GHz	8.84	35.00	3.20	11.60	3.50	40.80
11	1.8GHz-4GHz	9.04	35.00	4.70	8.60	4.75	40.80
12	4GHz-6GHz	10.36	35.00	7.10	6.70	6.09	40.80
13	6GHz-18GHz	15.35	35.00	11.60	7.50	5.45	40.80
14	8GHz-14GHz	15.35	35.00	11.60	7.50	5.45	40.80
15	14GHz-18GHz	15.35	35.00	11.60	7.50	5.45	40.80

- Band Number: A number assigned to each band for internal computer control
- Freq. - Band: Frequency range of the band
- Pi Amp (dBm): Input power level from the source to the amplifier
- Amp Gain: Gain of the amplifier provided by the manufacturer
- Cable Loss: System cable loss over 25 ft of coaxial cable
- Pi Ant: Expected output power from the amplifier to the antenna
- Ave. Num. Gain: Transmit antennae gain
- ERP (W): Calculated effective radiated power in WATTS

4.2.2 LLSF Data Processing

The unprocessed acquired LLSF data provided the actual onboard E-Field levels in dBm. These data represented the composite of system noise, ambient E-Fields, and the transmitted E-Fields. As with SCAL, these data were corrected for manufacturer antenna factors and system and cable losses. After applying the appropriate corrections, the data were converted to engineering units (V/m) and finally extrapolated to determine the anticipated internal E-Field levels had the S-76 been irradiated at the full threat levels identified in Figure 4-13. The following algorithms were applied in each step of the LLSF data processing:

- $EF_{dBuV/m} = EF_{dBm} + AF + IL$

  where:
  - EF_{dBm} is the raw data acquired from the receive spectrum analyzer.
  - AF is the manufacturer-supplied antenna factor.
  - IL is the receive system equipment and cable loss.
  - $EF_{dBuV/m}$ is EF_{dBm} corrected for losses and antenna factors.

- $EF_{FTV/m} = EF_{V/m} \bullet ER$

  where:
  - ER is the full threat extrapolation ratio which equals the full threat level divided by the SCAL level.
  - FT is the full threat environment as a function of frequency identified in Figure 4-10.
  - $EF_{FTV/m}$ is the calculated (extrapolated) E-Field level expected to have existed onboard the S-76 had the transmitted LLSF E-Field levels been at full threat.
  - $EF_{V/m}$ equals the $EF_{dBuV/m}$ converted to V/m

- $AT_{dB} = EF_{V/m} - SCAL_{V/m}$

  where:
  - AT_{dB} is the calculated attenuation level in decibels.

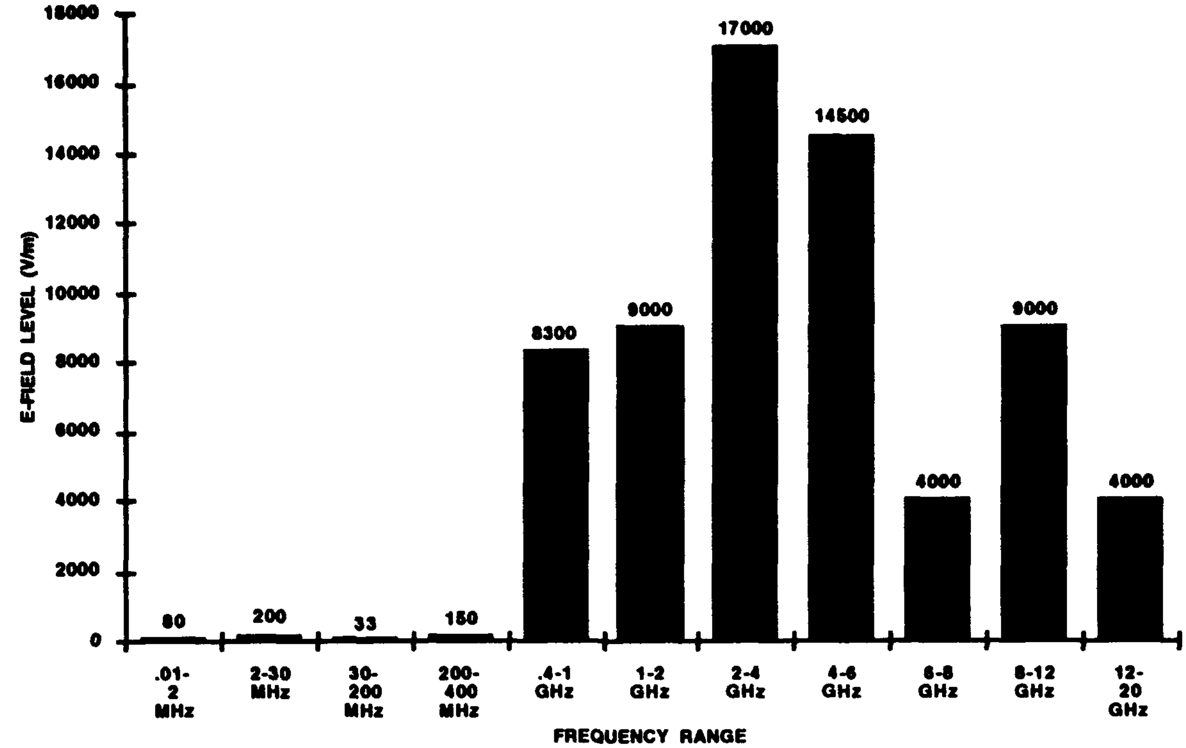


Figure 4-13. Full Threat Environment E-Field Levels

4.2.3 Summary Of Results

A summary of the aircraft's minimum and maximum average attenuation levels, derived from the detailed LLSF data in Volume II, is provided in Figures 4-14 and 4-15. Figure 4-14 presents the results from the S-76 being irradiated "side-on" and Figure 4-15 presents the results of the S-76 being irradiated "head-on." As is evident from the attenuation charts, considerably more attenuation was experienced when the S-76 was irradiated "head-on." These results were expected as there is a metallic fire wall between the electronics bay in the nose of the S-76 and the cabin. Additionally, in most instances, the greatest attenuation was experienced in the cargo area (R5) and the minimum in the pilot instrumentation area (R3).

It is important to realize that each of the data points presented in Figures 4-14 and 4-15 represent only a maximum and minimum of the 1000 data points acquired for each band. Therefore, the reader should refer to the detailed LLSF data provided in Volume III for an accurate perspective of the attenuation levels.

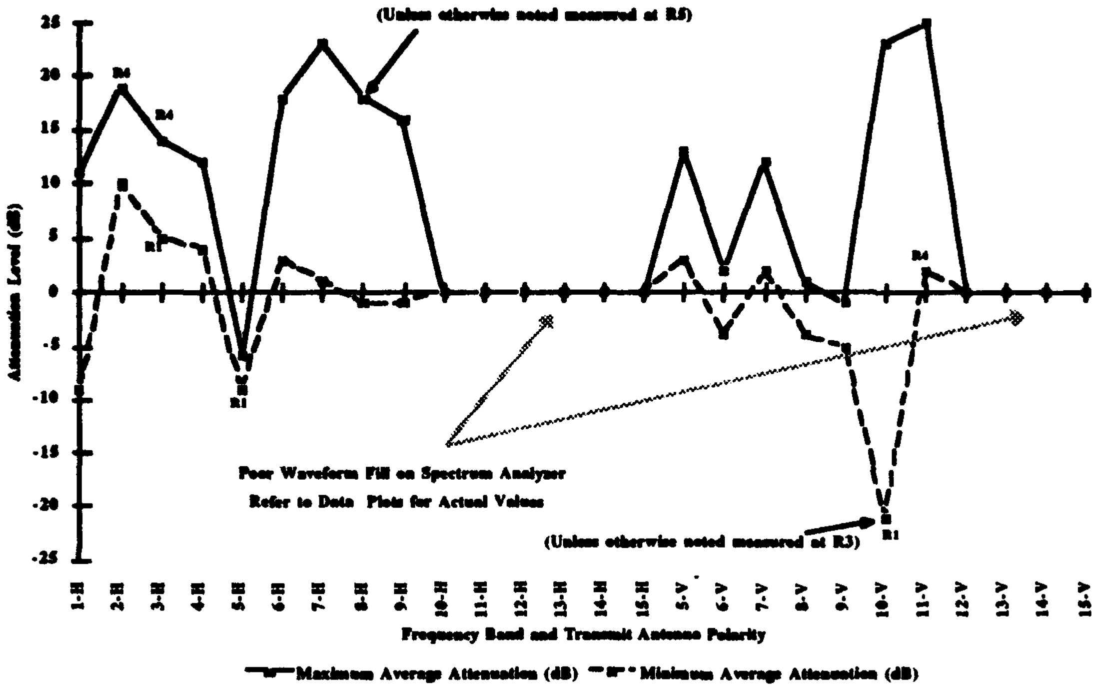


Figure 4-14. S-76 Calculated Attenuation Levels (T1)

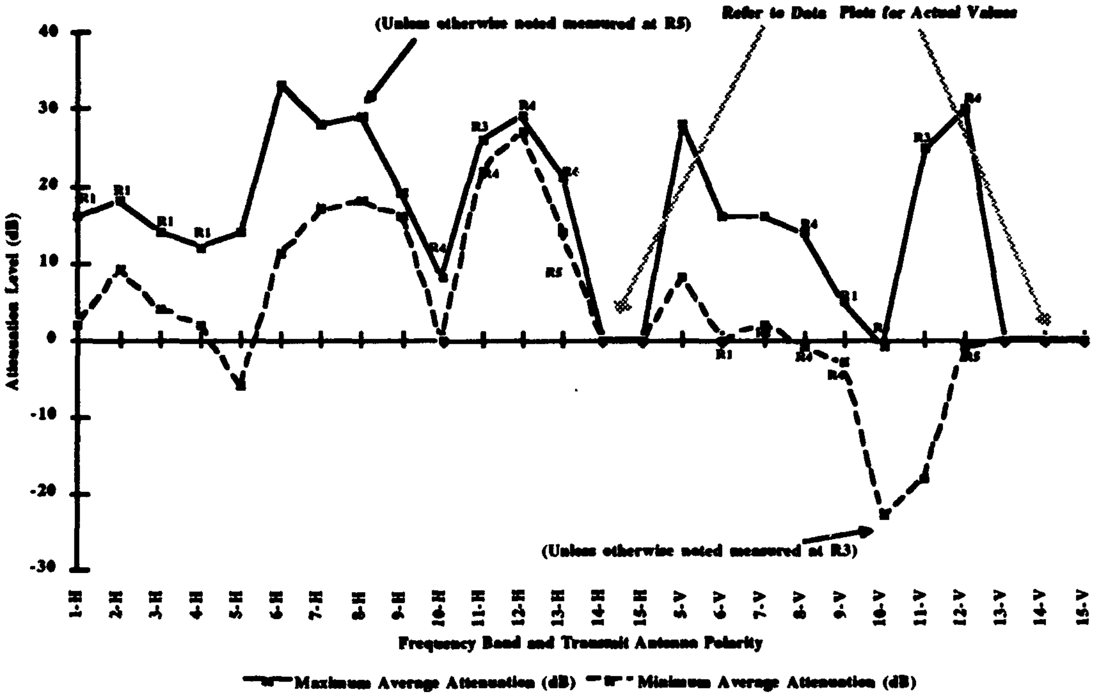


Figure 4-15. S-76 Calculated Attenuation Levels (T2)

4.3 Low Level Swept Coupling

The LLSC tests were performed to measure the current induced in cable bundles as a result of the S-76 being exposed to low level E-Field irradiation. The induced cable currents were measured over the frequency range of 10 kHz to 1 GHz.

4.3.1 LLSC Technical Approach

The LLSC cable current measurements were performed in accordance with the guidelines established in DO-160C by attaching current monitor probes on the various equipment cable bundles as indicated in Figure 4-16 and 4-17. During the aircraft irradiation, the induced current levels were monitored on a spectrum analyzer and transferred to a computer for follow-on analysis. The LLSC cable current measurements were made in parallel with the E-Field measurements.

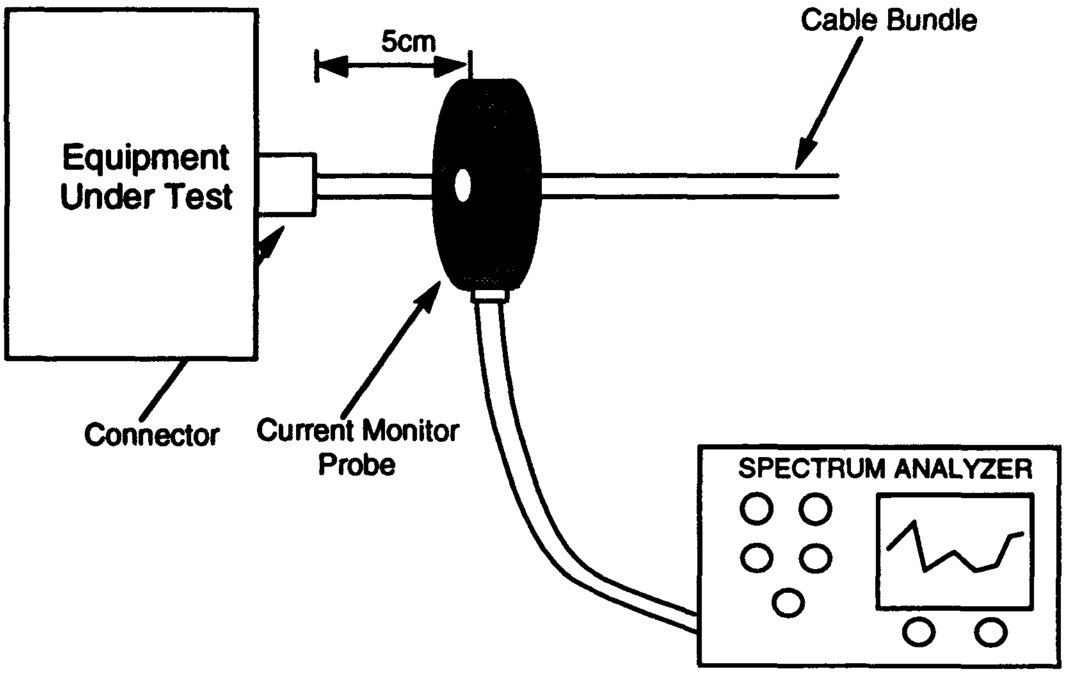


Figure 4-16. Current Monitor Probe Configuration

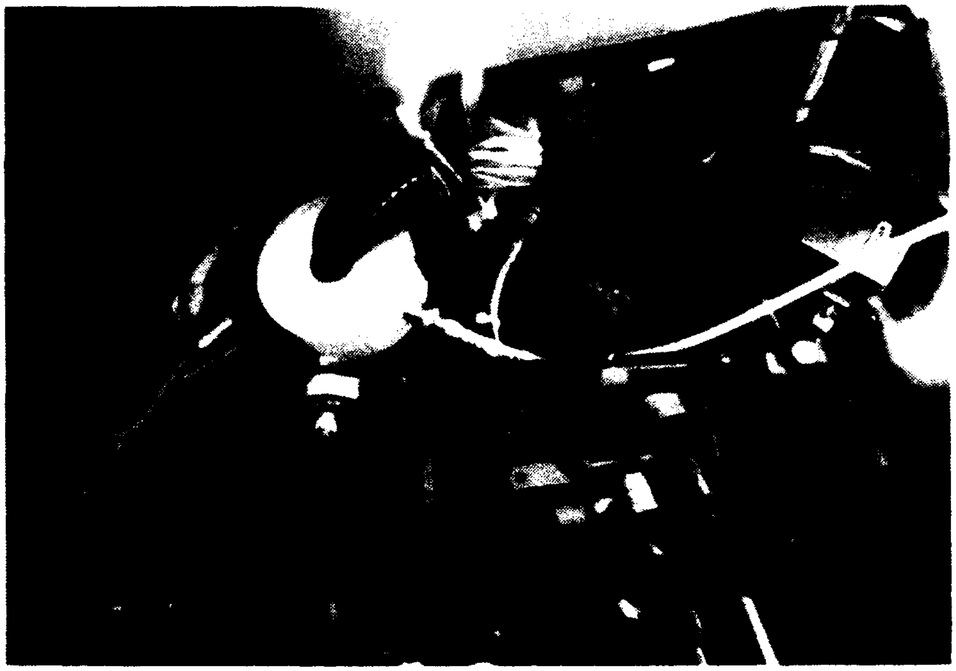


Figure 4-17. Current Monitor Probe Configuration Photograph

As with the E-Field measurements, current monitor sensors were placed in various receive locations as identified in Table 4-3.

Table 4-3. LLSC Cable Current Test Locations

Configuration			
Transmit Location	**Number**	**High Frequency Probe**	**Low Frequency Probe**
1	1	Pilot Display Unit - R3	Co-Pilot Display Unit - R1
1	2	Co-Pilot Display Unit - R1	Pilot Display Unit - R3
1	3	Pilot Display Unit - R3	Co-Pilot Display Unit - R1
1	4	Altitude Indicator - R3	Fire Sensor - R6
1	5	Fire Sensor - R6	Altitude Indicator - R3
2	1	Pilot Display Unit - R3	Co-Pilot Display Unit - R1
2	2	Co-Pilot Display Unit - R1	Pilot Display Unit - R3
2	3	Pilot Display Unit - R3	Co-Pilot Display Unit - R1
2	4	Altitude Indicator - R3	Fire Sensor - R6
2	5	Fire Sensor - R6	Altitude Indicator - R3

4.3.2 LLSC Data Processing

The acquired LLSC data provided the actual onboard induced cable current levels in dBm. These data represented the composite of system noise and the intended cable currents. As with the LLSF measurements, these data were corrected for manufacturer current monitor probe factors, system losses, and cable losses. After applying the appropriate corrections, the data were converted to engineering units (A) and finally extrapolated to determine the anticipated induced cable current levels had the S-76 been irradiated at the full threat levels identified in Figure 4-13. The following algorithms were applied in each step of the LLSF data processing:

- $CC_{dBuA} = CC_{dBm} - PF + IL$
  where:
  - CC_{dBm} is the raw data acquired from the receive spectrum analyzer.
  - PF is the manufacturer-supplied current monitor factor.
  - IL is the receive system equipment and cable loss.
  - CC_{dBuA} is CC_{dBm} corrected for losses and current monitor probe factors.

- $CC_{FTA} = CC_A \bullet ER$
  where:
  - ER is the full threat extrapolation ratio which equals $FT/SCAL_{V/m}$.
  - CC_A is the CC_{dBuA} converted to A.
  - CC_{FTA} is the calculated (extrapolated) cable current level expected to have existed onboard the S-76 had the LLSC E-Field levels been full threat.

4.3.3 Summary Of Results

Per the requirements of DO-160C, component HIRF testing may be accomplished by directly injecting current on the component's cable bundles. The prescribed current levels (as a function of frequency) correspond to those anticipated to be induced were the component exposed to full threat HIRF levels.

During the S-76 LLSC data processing, the measured induced cable currents, resulting from low level E-Field irradiation, were extrapolated to calculate the anticipated current levels had the S-76 been irradiated at full threat. Summary results, over the frequency range of 10 kHz to 1 GHz, have been charted comparing the DO-160C and actually measured levels in Figures 4-18 through 4-21. As indicated, the extrapolated S-76 LLSC levels are significantly higher at many frequencies than those required by DO-160C indicating the S-76, and perhaps rotorcraft in general, are more susceptible and may require greater degrees of protection for wiring harnesses and instrument systems.

The supporting detailed data plots may be found in Volume II of this report.

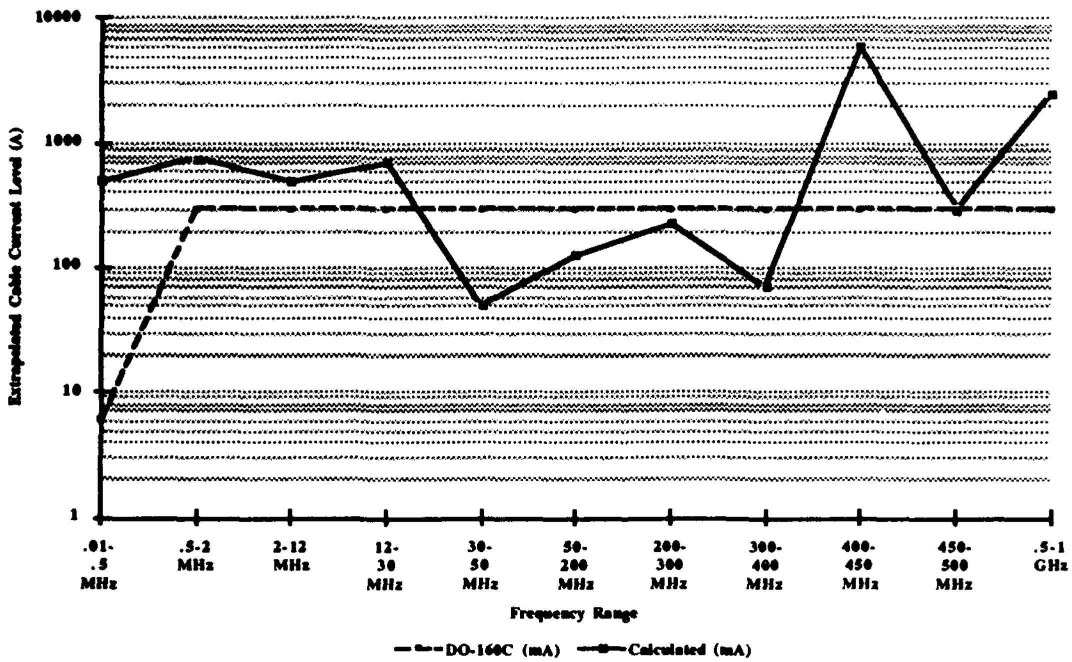


Figure 4-18. Pilot Display Unit Extrapolated Cable Current Levels

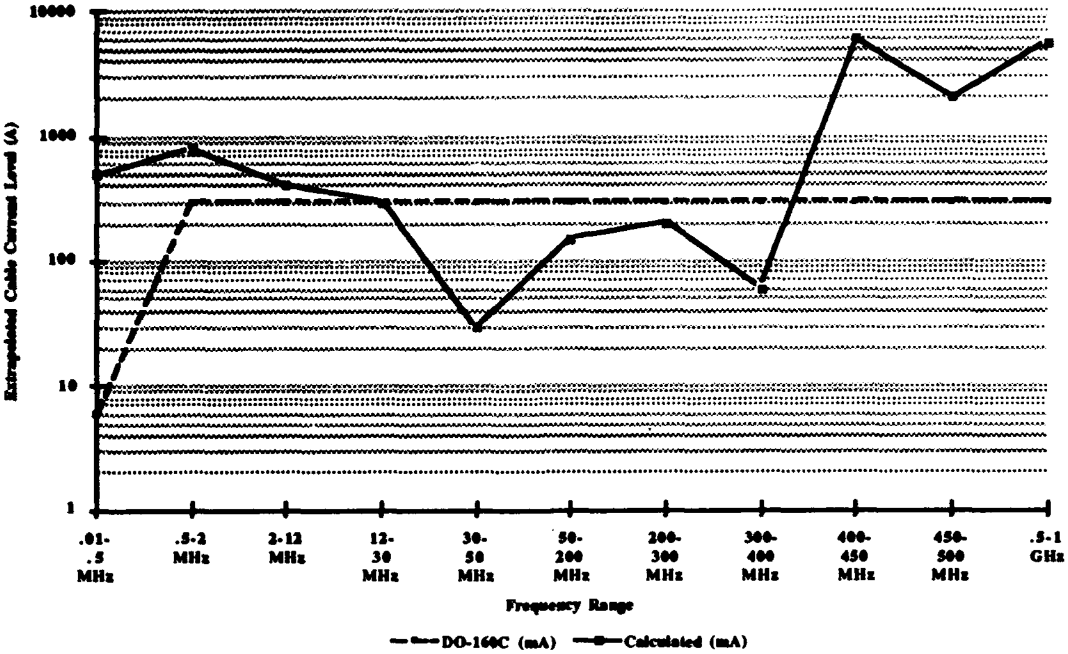


Figure 4-19. Co-Pilot Display Unit Cable Extrapolated Current Levels

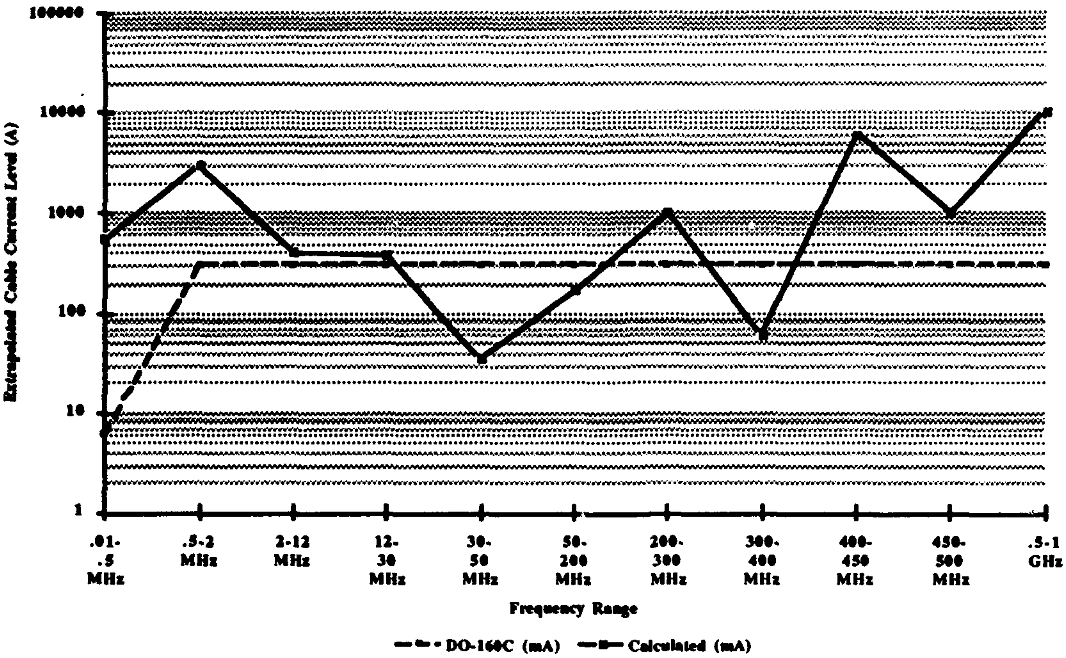


Figure 4-20 Fire Sensor Extrapolated Cable Current Levels

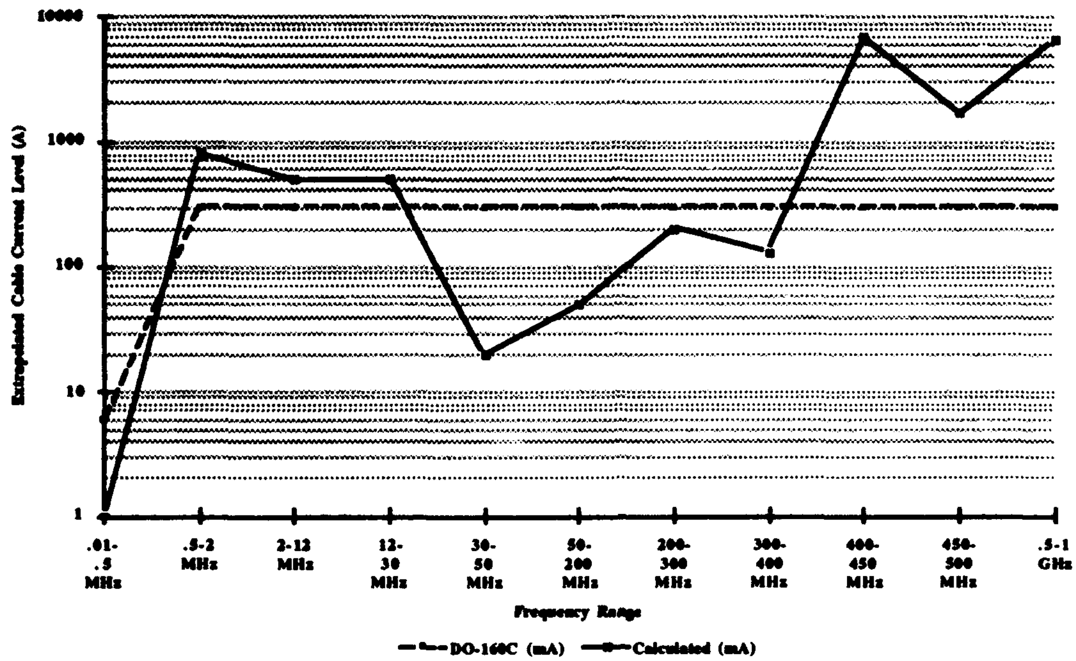


Figure 4-21. Altitude Indicator Extrapolated Cable Current Levels

5. S-76 FLIGHT TESTS

The flight tests were performed to evaluate the effects of existing "real world" emitters on the S-76's flight instruments. During the flight tests, video recorders were used to monitor and record any potential instrument disruptions while a combined receive and control node (Figures 5-1 and 5-2) monitored and recorded the onboard E-Field levels.

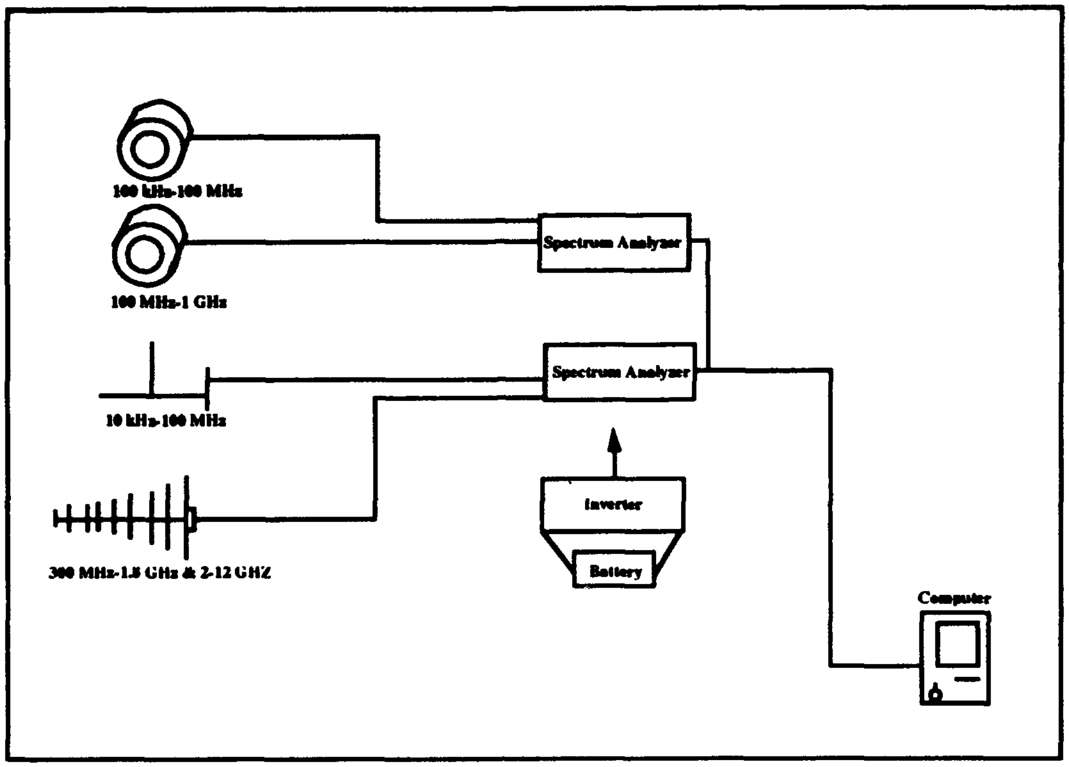


Figure 5-1. Flight Test Receive and Control Node

Figure 5-2. Flight Test Receive and Control Node Photograph

Due to poor weather conditions and coordination problems with the OTHB personnel, the flight tests were conducted in two phases. During both phases, the emitters consisted of both pulsed and CW transmission characteristics. It was determined during the Phase I tests that modifications to the receive spectrum analyzer set-up parameters would be necessary to compensate for the relatively narrow pulse width of the pulsed emitters and point frequency of the CW emitters. The modifications, consisting of increasing the resolution bandwidth, decreasing sweep rate, and decreasing span per division, were implemented during Phase II of the flight tests. In addition to the spectrum analyzer set-up modifications, numeric corrections were necessary to convert the measured pulsed emitter average levels to the actual peak levels.

5.1 Flight Test Data Processing

The S-76 flight test data were processed to compensate for manufacturer antenna factors and cable losses. Also, in the cases where the S-76 was irradiated by pulsed emitters, numeric corrections were applied to convert the measured average to peak levels. The following describes the various algorithms used during the data processing:

- $EF_{AVdBuV/m} = EF_{AVdBm} + AF + IL$

  where:

  - EF_{AVdBm} is the average raw data acquired from the receive spectrum analyzer in dBm.
  - AF is the manufacturer supplied antenna factor.
  - IL is the receive system equipment and cable loss.
  - $EF_{dBuV/m}$ is EF_{dBm} corrected for losses and antenna factors.

- $EF_{AVdBV/m} = EF_{AVdBuV/m} - 107$

  where:

  - $EF_{AVdBV/m}$ is the $EF_{AVdBuV/m}$ converted to dB micro Volts
- $EF_{AVV/m} = \text{Log}^{-1}(EF_{AVdBuV/m}/20)$

  where:

  - RSBW is the spectrum analyzer resolution bandwidth.
  - DC is the duty cycle of the pulsed emitter.
  - $EF_{PKdBV/m}$ is the peak E-Field level corrected for the pulsed emitters duty cycle.
  - .1 is a scaling factor provided by the spectrum analyzer manufacturer.

5.2 Phase I Flight Tests Descriptions

The Phase I flight tests included fly-by tests of emitters at the FAATC [High Hover Calibration (HHC), ASR-9, and High Frequency (HF) transmitters], the Over the Horizon Back Scatter (OTHB) Radar in the area of Bangor, ME, and the PAVE PAWS Radar at Cape Cod, MA. The following describes the transmitter characteristics and a summary of the results for each test. As with the ground tests, the detailed processed data for the Phase I flight tests are contained in Volume II of this report.

5.2.1 HHC Flight Test

The HHC flight test was performed to calibrate the receive equipment in preparation for the PAVE PAWS and OTHB flight tests. During these tests, the ground test transmit antennae were raised forming a 45° angle with the ground, while the S-76 hovered at the ranges depicted in Figures 5-3 and 5-4.

During the HHC Flight tests, measurements were made with the S-76 oriented for both front and side irradiation. A summary of the onboard measured E-Field levels is provided in Figure 5-5.

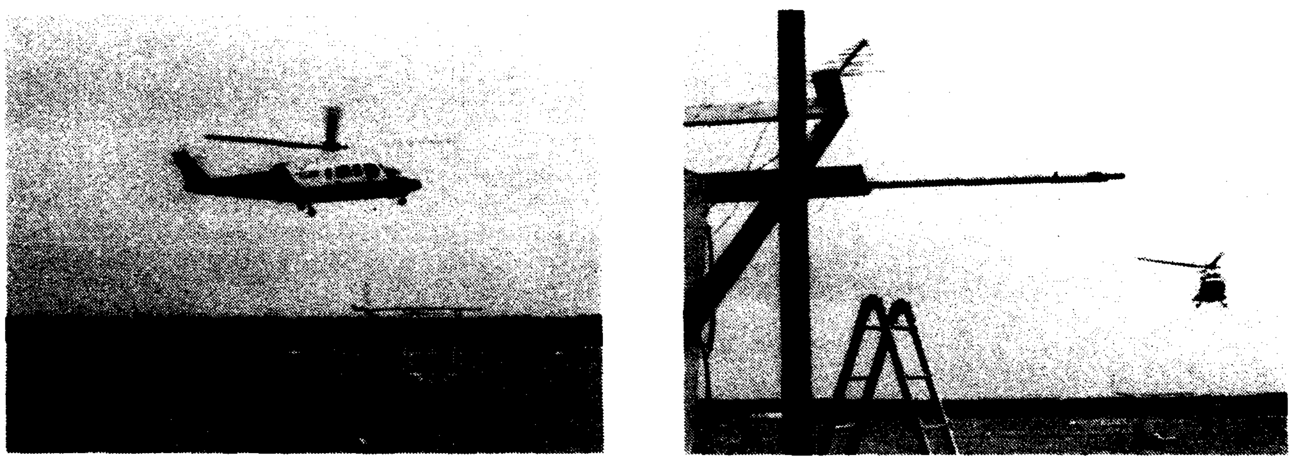


Figure 5-3. HHC Photographs

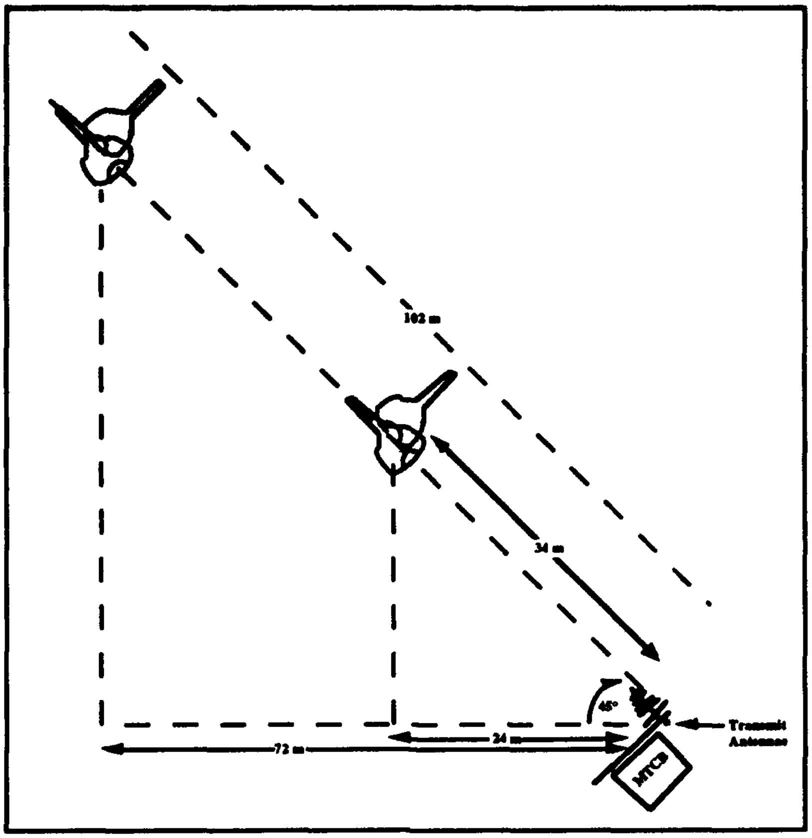


Figure 5-4. HHC Flight Profile

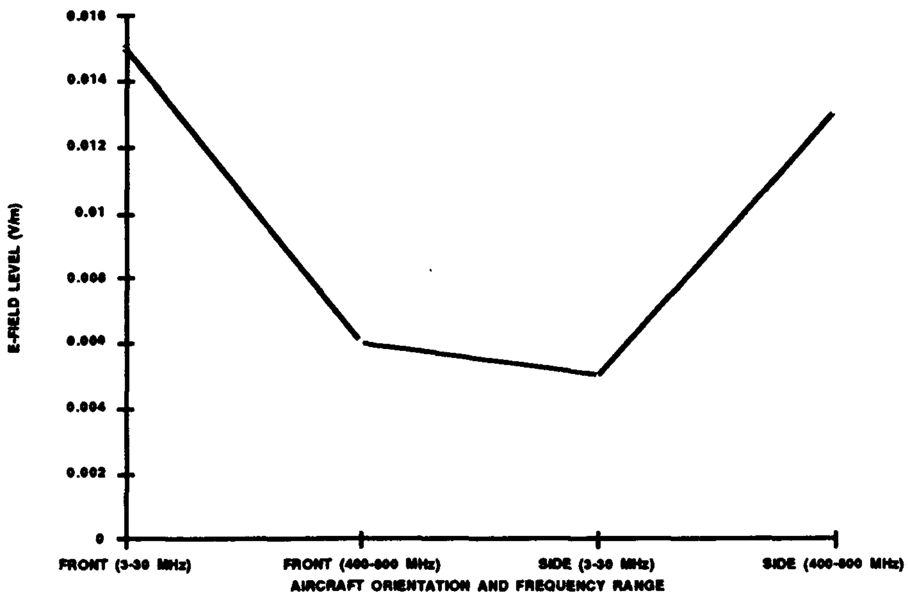


Figure 5-5. HHC Summary E-Field Levels

5.2.2 FAATC HF Transmitter Flight Test

During the FAATC HF Transmitter portion of the Phase I flight test, the S-76 was flown directly over the transmitting antennae as indicated in Figure 5-6. Initially, it was thought the transmitter would be operating with an ERP in the megawatt (MW) range. Upon completion of the test, it was determined that the transmitter was operating at only one kilowatt (kW) over a frequency range of 3-30 MHz. As a result, no significant E-Field levels were measured and no instrument disruptions occurred.

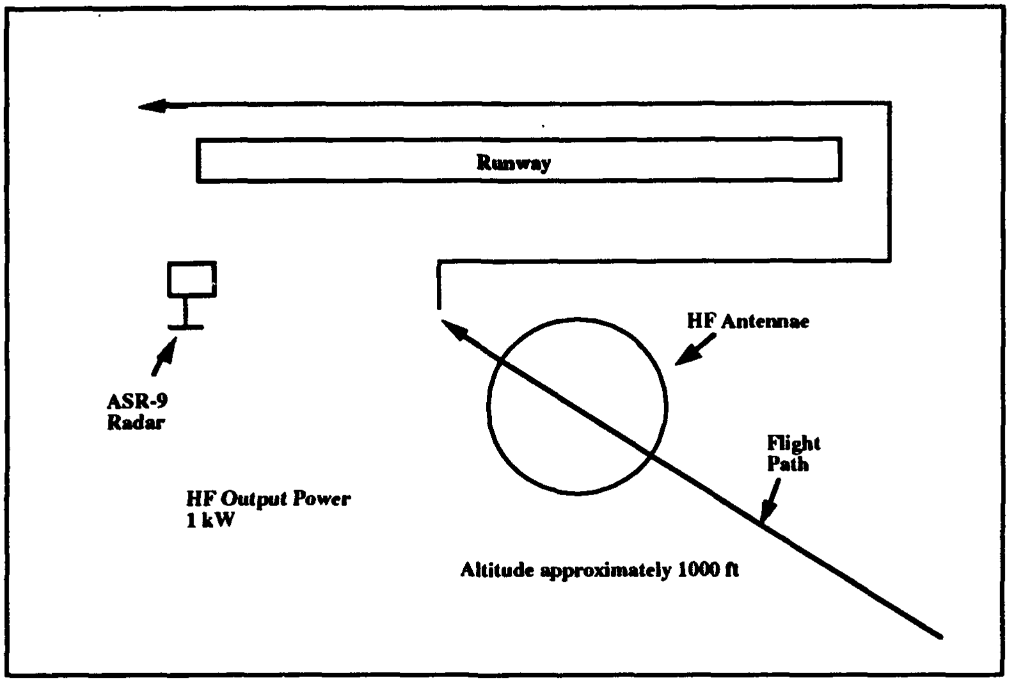


Figure 5-6. ASR-9 and HF Flight Profile

5.2.3 ASR-9 Flight Test

Since the ASR-9 is a directional transmitter, the flight profile for the ASR-9 flight test (also depicted in Figure 5-6) did not include a direct over-flight. Unlike the HF transmitter, the ASR-9 is a pulsed radar operating at a frequency range of 2-4 GHz and relatively low power.

Due to unknown causes, the ASR-9 E-Field data were not stored to disk during the actual measurements, and therefore are not available. It should be noted, however, that no instrument disruptions occurred.

5.2.4 OTHB Phase I Flight Test

Problems, such as poor weather and coordination issues with the Air Force operations personnel during the OTHB portion of the Phase I flight test, resulted in lower than desired output power levels, producing a less than optimum outcome. Although two flights were performed, the radar was operating below 1/4 power corresponding to an ERP of only 44 kW at a frequency of 21 MHz.

While excessive cloud cover made it difficult to follow an accurate flight path, Figure 5-7 depicts the intended pattern for the OTHB Phase I flight test.

Although the output power level was lower than expected, one disruption to an analog fuel flow indicator was noted. Attempts to repeat the disruption were not successful.

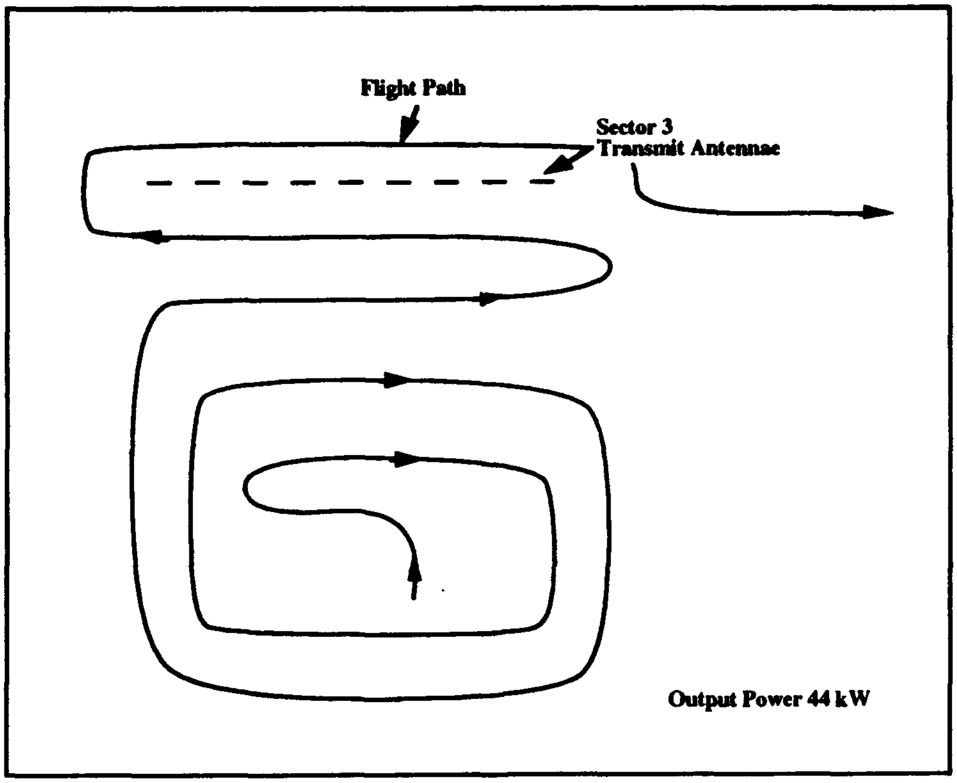


Figure 5-7. OTHB Phase I Flight Profile

5.2.5 PAVE PAWS Flight Test

As with the FAATC HF transmitter, the PAVE PAWS output levels were found to be lower than expected. This situation however, was not due to coordination issues, but rather to the normal operating characteristics of the transmitter. As indicated in Figure 5-8, two passes at varying altitudes were performed. During both passes the PAVE PAWS was operating between 400 and 800 MHz at an ERP of 1 kW.

No instrument disruptions occurred during the PAVE PAWS tests.

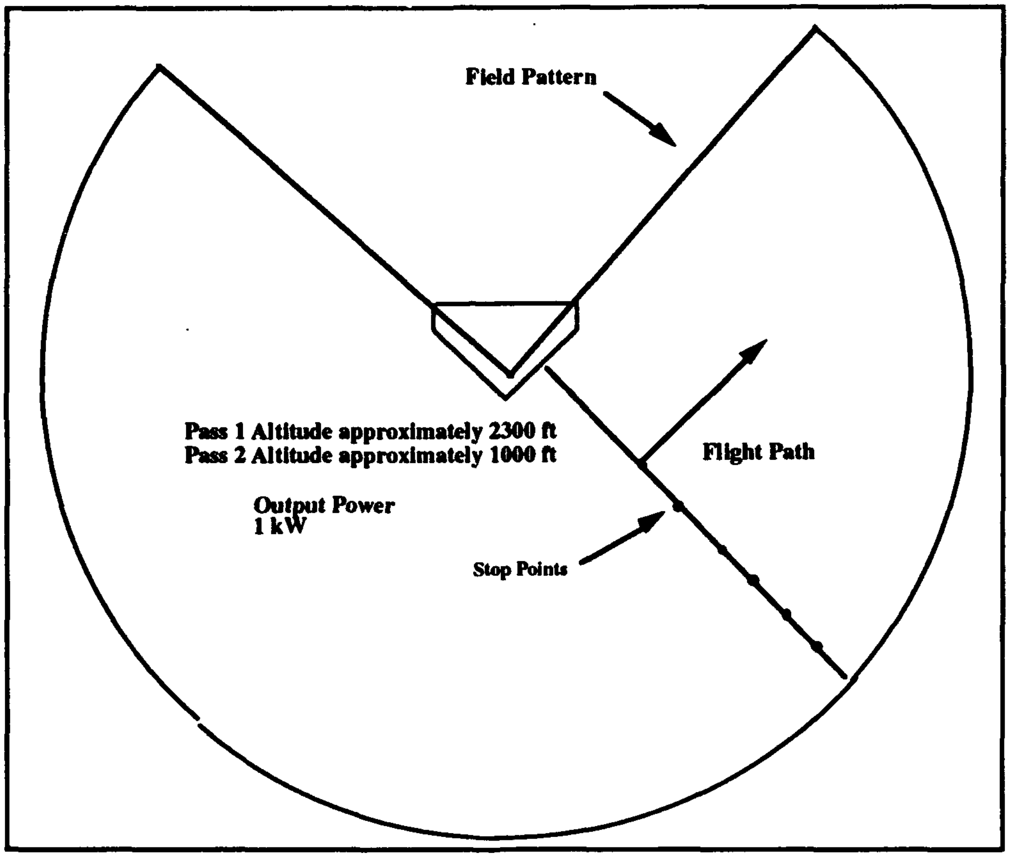


Figure 5-8. PAVE PAWS Flight Profile

5.3 Phase II Flight Tests

The Phase II flight tests included fly-by tests of emitters at the Rome Laboratory Radar Test Range (FPS-65 and FPS-16), Griffiss Air Force Base, NY, and the Over the Horizon Back Scatter (OTHB) Radar in the area of Bangor, ME. Unlike the previous flight test, the Phase II tests conducted at Rome Laboratory were performed using operational transmitters at the United States Air Force (USAF) radar test range. This environment enabled the pilot and onboard test system operator to maintain continuous voice communications with the ground operators. Additionally, the S-76's range from the each active transmitter was monitored and recorded.

5.3.1 FPS-16 Flight Test

During the FPS-16 flight test, the S-76 pilot flew an angular profile depicted in Figure 5-9. The radar was operating at 29 GW peak power on a transmit frequency of 5650 MHz with a duty cycle of 6.4 x 10^{-4}.

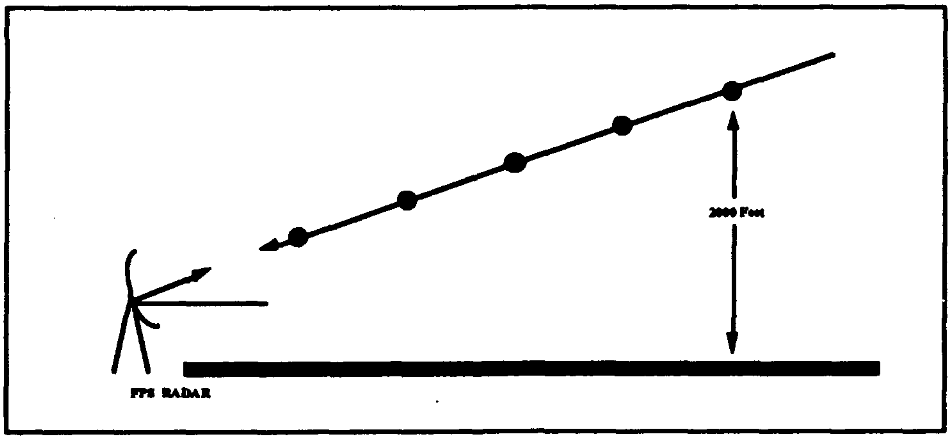


Figure 5-9. FPS-16 and FPS-65 Flight Profile

A comparison of the expected-to-measured E-Field levels is provided in Figure 5-10. While the measured levels are considerably lower than expected, the aircraft's attenuation of approximately 20 dB accounts for a decrease of one order of magnitude. The approximation of 20 dB was obtained from the Volume II data plot for side irradiation with the receive antenna in the center of the cabin area, which most closely approximated the FPS-16 flight test configuration.

Although disruptions to the test system computer's cathode ray tube (CRT) occurred, no disruptions to the S-76 flight instruments were noted during the FPS-16 test. The CRT disruptions were not attributed to either the FPS-16 or FPS-65 and may have been the result of other transmission sources active in the area.

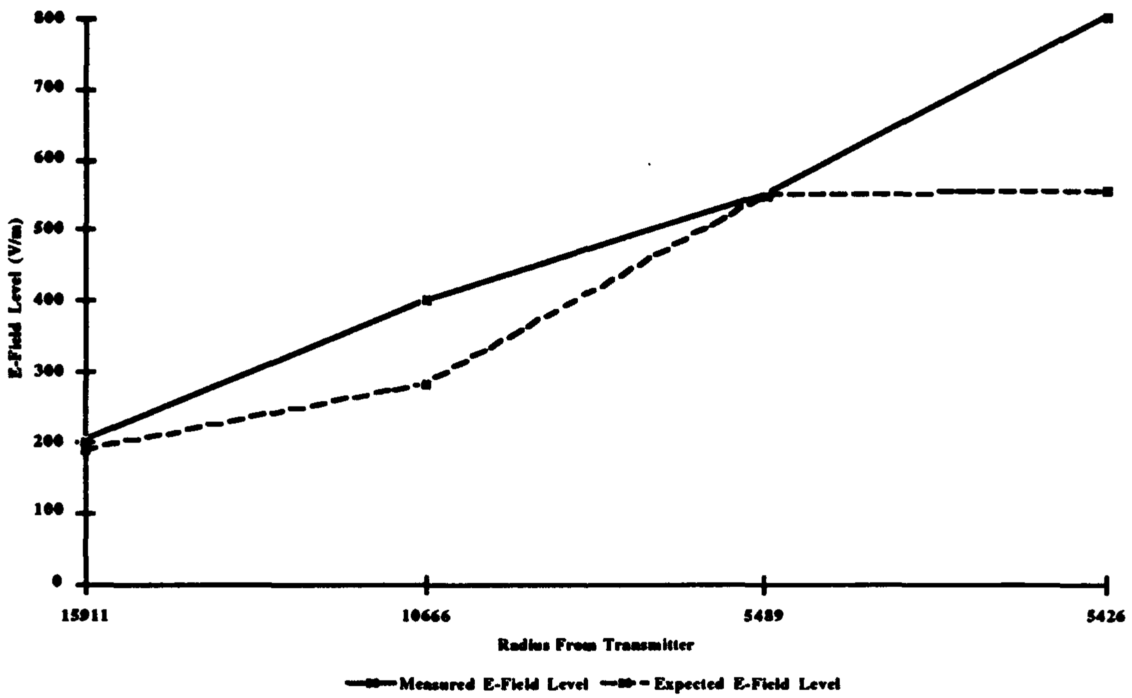


Figure 5-10. FPS-16 Measured and Expected E-Field Levels

5.3.2 FPS-65 Flight Test

During the FPS-65 flight tests, the S-76 pilot also flew an angular profile depicted in as Figure 5-9. The radar was operating at 6.3 GW peak power on a transmit frequency of 1255 MHz with a duty cycle of 2.22 x 10^{-4}.

A comparison of the expected to measured E-Field levels is provided in Figure 5-11. While the measured levels are considerably higher than expected, the aircraft's gain of approximately 20 dB accounts for a decrease of one order of magnitude. The approximation of 20 dB was obtained from the Volume III data plot for side irradiation with the receive antenna in the center of the cabin area which most closely approximated the FPS-65 flight test configuration.

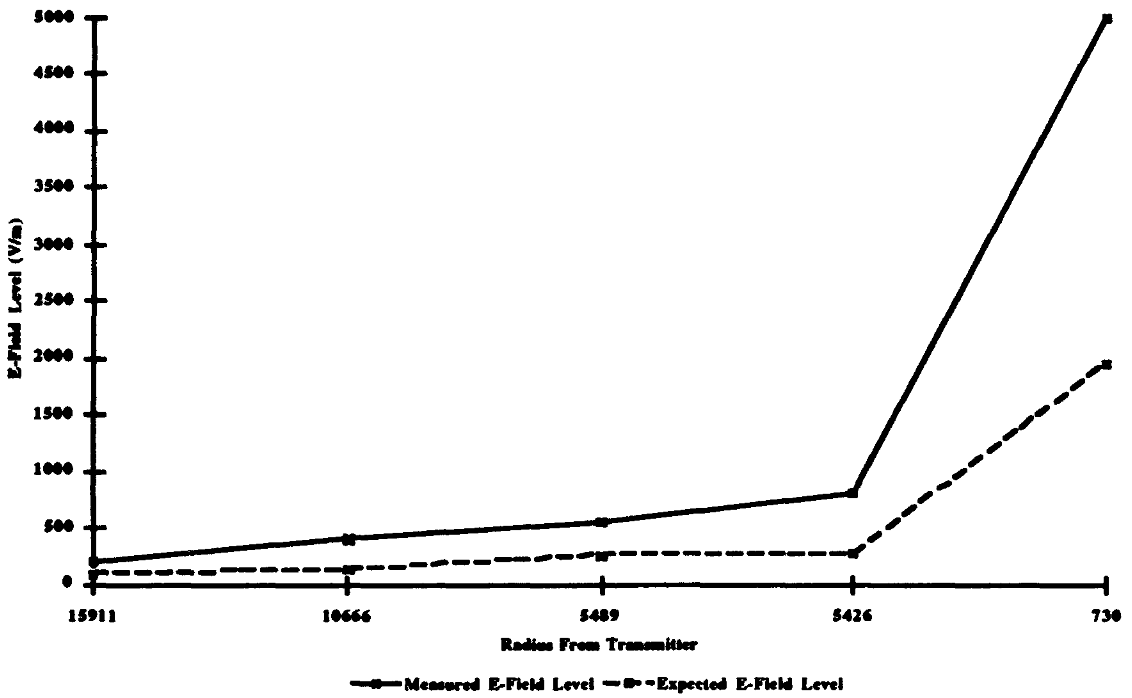


Figure 5-11. FPS-65 Summary Results

No disruptions to the S-76 flight instruments were noted during the FPS-16 test.

5.3.3 OTHB Phase II Flight Test

A modified profile was flown during the second OTHB flight test. This modification occurred primarily due to information that a side lobe existed around or directly over the transmit antennae array. As indicated in Figure 5-12, the flight profile included circling and flying directly over the antenna array. Although repeated flights were made, the side lobe was not encountered.

During the test, the OTHB transmitter was operating at 21 MHz with an ERP of 251 kW. Upon completion of the test, the radar's output power level was verified with the OTHB operations personnel to ensure there had been no coordination problems.

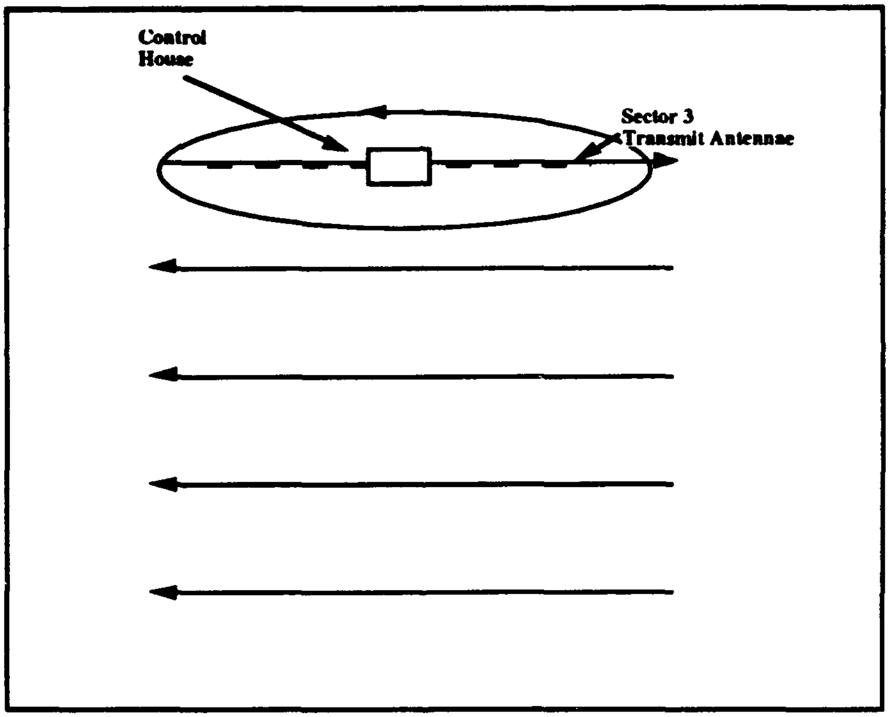


Figure 5-12. OTHB Phase II Flight Profile

Figure 5-13 depicts the Phase II OTHB flight tests onboard E-Field levels and corresponding radius' from the transmitter. Similar to the Phase I tests, disruptions to both analog fuel flow indicators were experienced with sporadic disruptions to the landing gear down indicators. Unlike the first OTHB test, the disruptions to the fuel flow indicators were repeatable (as indicated in Figure 5-13) and typically occurred at an orientation perpendicular to the control building in the center of the transmit array.

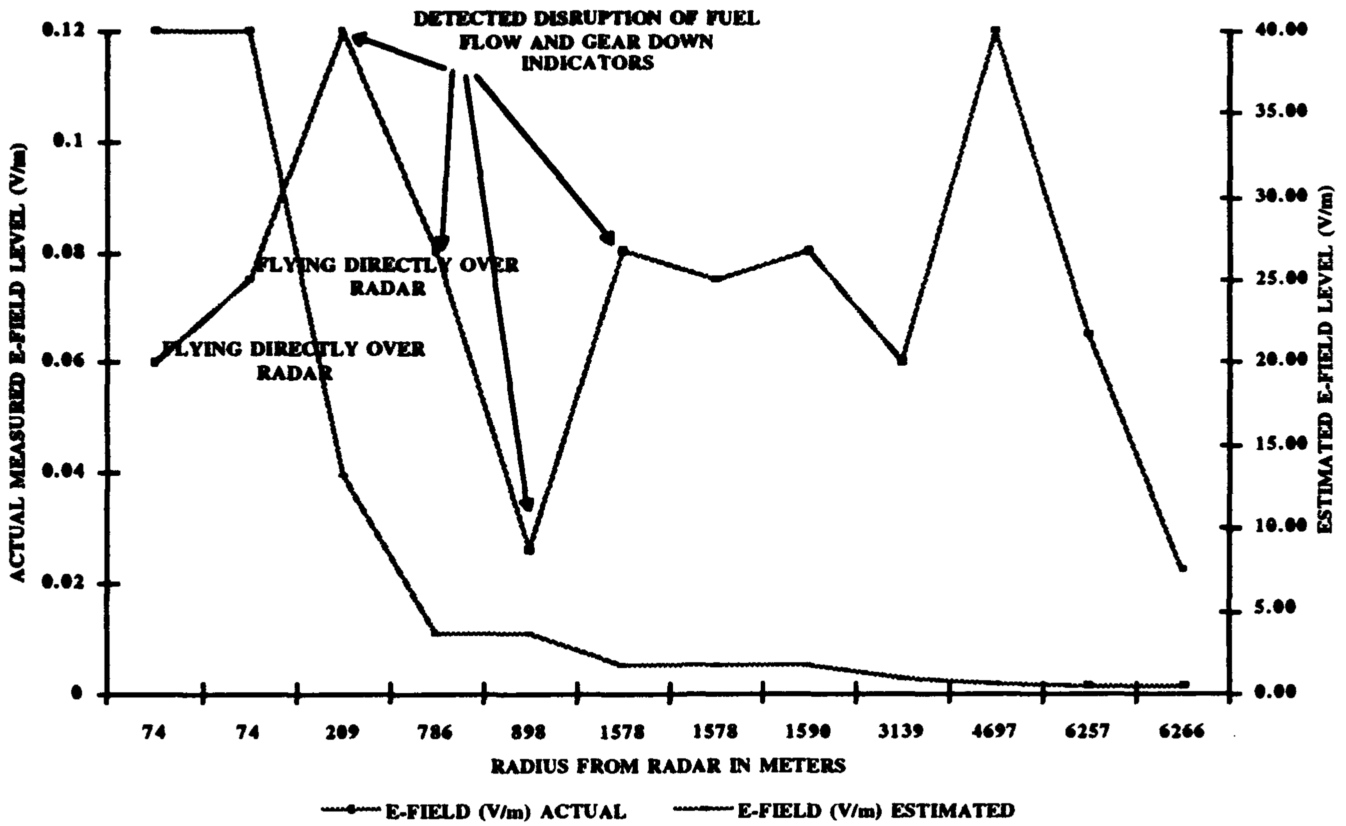


Figure 5-13. OTHB Phase II Summary Results

6. TECHNICAL CONSIDERATIONS

One of the purposes of the S-76 HIRF test project was to evaluate HIRF test methodologies, both from a technical and a cost perspectives. During the project, certain system configuration decisions were made based on several factors including technical merit, cost, and availability. In some cases, the cost and availability factors outweighed the technical merit resulting in less than a technically ideal approach. Additionally, during the actual HIRF tests and data analysis phases of the project, anomalies were encountered which warrant discussion in this report. This section addresses technical issues associated with the S-76 HIRF test project and, where possible, provides the rationale for decisions and explanations of technical anomalies.

6.1 Signal-To-Noise Ratio

As is the standard practice when performing LLSC and LLSF tests, SCAL tests were conducted prior to placement of the S-76 in the test area. During the SCAL tests, the signal sources were set to the maximum output power levels possible without causing amplifier overload and/or helix current fault conditions. Typically, the source power levels were sufficient to provide a minimum of 10 dB signal-to-noise ratio (SNR) within spot regions in each band. However, while performing the aircraft irradiation portion of the LLSC tests, several factors, including aircraft attenuation, resulted in an SNR below 3 dB. The technical ramifications of this situation become immediately evident when extrapolating the LLSC data to the full-threat levels. With SNRs between 0 and 3 dB, it was not clear what the actual onboard signal levels were and the results reflect extrapolation of the system noise and ambient E-Field levels. Therefore, it was invalid to extrapolate the data with a low SNR to full-threat.

6.1.1 Signal-To-Noise Ratio Assessment

Aircraft attenuation is determined by subtracting the SCAL from the measured aircraft irradiation levels, and any instance where the aircraft's attenuation equaled or exceeded the SCAL SNR, the result is an observed SNR of 0 dB. As such, the following assessments can be made.

- In such cases, it is invalid to extrapolate the signal to full-threat to provide expected levels had the aircraft been irradiated at full-threat.

- Since the actual signal is at or below the noise floor, extrapolation of the noise floor to full-threat represents a worst case scenario.

- Where the LLSF SNR was 0 to 3 dB, the calculated attenuation levels can only be identified as greater than or equal to the SCAL SNR.

6.1.2 Signal-To-Noise Ratio Resolution

When reviewing the Volume II data plots, the reader must realize that, where the corresponding onboard E-Field measurement SNR is less than 3 dB, the aircraft attenuation plot represents the minimum aircraft attenuation.

6.2 Antennae Mount Differences

During SCAL, the receive antennae were mounted on non conductive mounts made of wood and polyvinyl-chloride (PVC) pipe. The antennae had been calibrated by a laboratory and the antenna factors provided are provided in Appendix I.

Due to the shock and vibration requirements for in-flight tests, it was necessary to mount the receive antennae on metal racks specially designed to mount on floor rails inside the S-76. The change in the antennae mount configuration is of concern as it may have resulted the invalidation of the laboratory provided antenna factors.

6.2.1 Antennae Mount Differences Assessment

Upon completion of the Phase II flight test, a laboratory experiment was conducted to evaluate the potential effects of antennae mounts differing from the antenna calibration configuration. The experiment involved performing E-Field measurements in a non-conductive cavity with no external influences (i.e., metallic rack mounts, shelves, etc.) and comparing the results to measurements performed in the same cavity with metallic objects placed in close proximity to the receive antenna. To provide further insight into the effects of metallic objects, the above experiment was also performed using an isolated loop H-Field (Magnetic field) antenna.

The results obtained from the laboratory experiment indicated the measured E-Field levels were not significantly impacted (variations were consistently less than 5%) when metallic objects were placed in the vicinity of the receive antenna. However, when the experiment was repeated using an H-Filed antenna, the results were significantly different (variations were consistently greater than 30%).

6.2.2 Antennae Mount Differences Resolution

Since the data presented in this report reflect only E-Field measurements, the error introduced by the close proximity of metallic objects is not great enough invalidate the test results.

6.3 Use Of D-Dot Antennae

To accomplish the onboard E-Field measurements, a variety of antennae were used to cover the frequency range of 10 kHz to 18 GHz. The antennae used were larger than ideal considering the sizes of the apertures within the S-76. Similar to the issue discussed in Section 6.2, the use of antennae with relatively large dimensions could affect the manufacturer's provided antenna factors.

6.3.1 Use Of D-Dot Antennae Assessment

Use of smaller D-Dot antennae when performing onboard E-Field measurements could provide better data as they are less susceptible to the effects of relatively small apertures.

6.3.2 Use Of D-Dot Antennae Resolution

While the D-Dot antennae are more suited for use in smaller apertures, experience has shown they are less sensitive resulting in less than acceptable SNRs. Additionally, the D-Dot antennae are quite expensive and typically cannot be leased. Considering the above, the decision was made not to use D-Dot antennae for onboard E-Field measurements.

6.4 Replacement Of Monopole Transmit Antenna With Bazooka Dipole Antenna

LLSC tests were performed using a monopole transmit antenna. While using the monopole, little or no SNR was discernible over the frequency range of 10 kHz to approximately 12 MHz. Inspection of the monopole indicated poor contact between the antenna and the balun. To facilitate continuance of the tests, a Bazooka Dipole antenna was fabricated and used in place of the monopole. Replacement of the monopole invalidated the original SCAL measurements.

6.4.1 Replacement Of Monopole Transmit Antenna With Bazooka Dipole Antenna Assessment

Figure 6-1 provides the design details for the Bazooka Dipole. Upon inclusion in the test system configuration, significantly better SNRs were discernible over the frequency range of 10 kHz to 12 MHz.

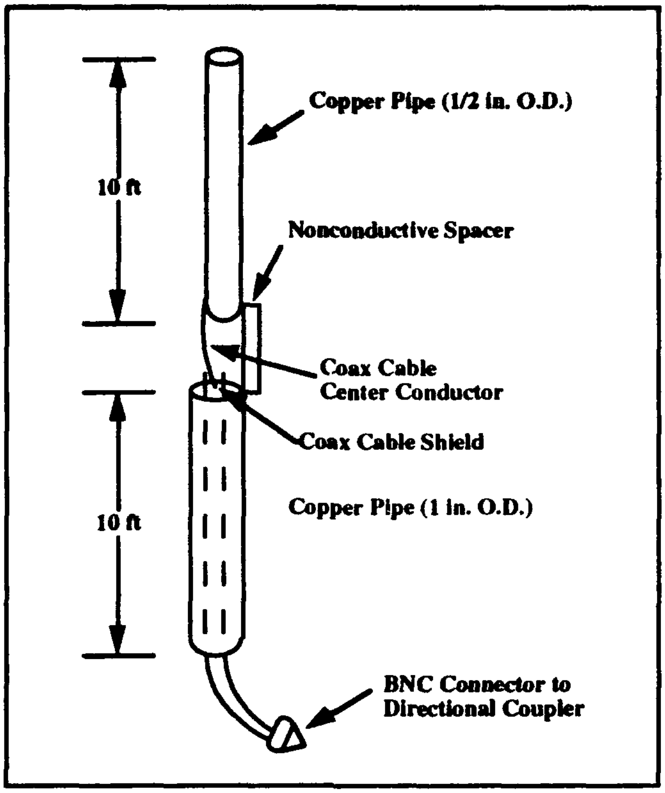


Figure 6-1. Bazooka Dipole

6.4.2 Replacement Of Monopole Transmit Antenna With Bazooka Dipole Antenna Resolution

To ensure consistency when performing the data analysis and extrapolation, a second set of SCAL measurements were performed using the Bazooka Dipole. The results of the second SCAL were used to process all data acquired after the antenna configuration change.

6.5 Ambient Radio Frequency Environment Changes

One purpose of the SCAL portion of ground tests was to establish the ambient radio frequency (RF) environment in the test area and test system noise levels for consideration when processing the acquired data. In some instances, ambient RF changes resulted in misrepresented aircraft attenuation and extrapolated levels.

6.5.1 Ambient Radio Frequency Environment Changes Assessment

The problem of a changing RF and/or system noise environment can be described as follows.

When SCAL ambient noise measurements are performed, the noise levels may appear as indicated in Figure 6-2.

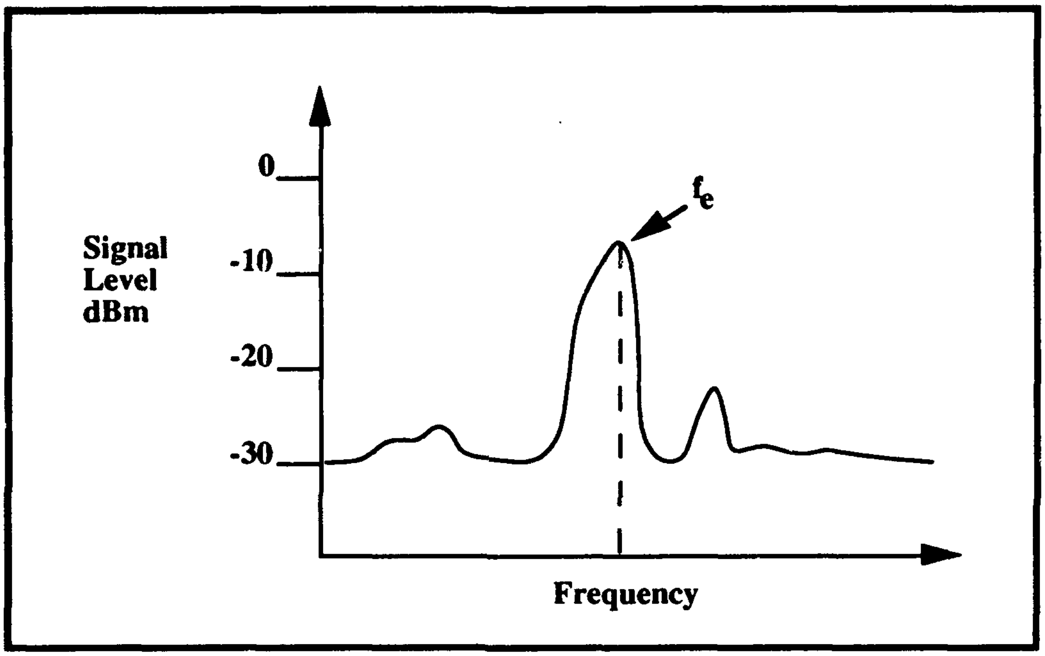


Figure 6-2. SCAL Ambient Noise Level

Once the noise levels are recorded, the transmitter is turned on and another measurement is made resulting in the signal-plus-noise level indicated in Figure 6-3. In both cases, the E-Field levels at frequency f_e are primarily due to local transmitters operating at higher power levels than the intended LLSC transmitters.

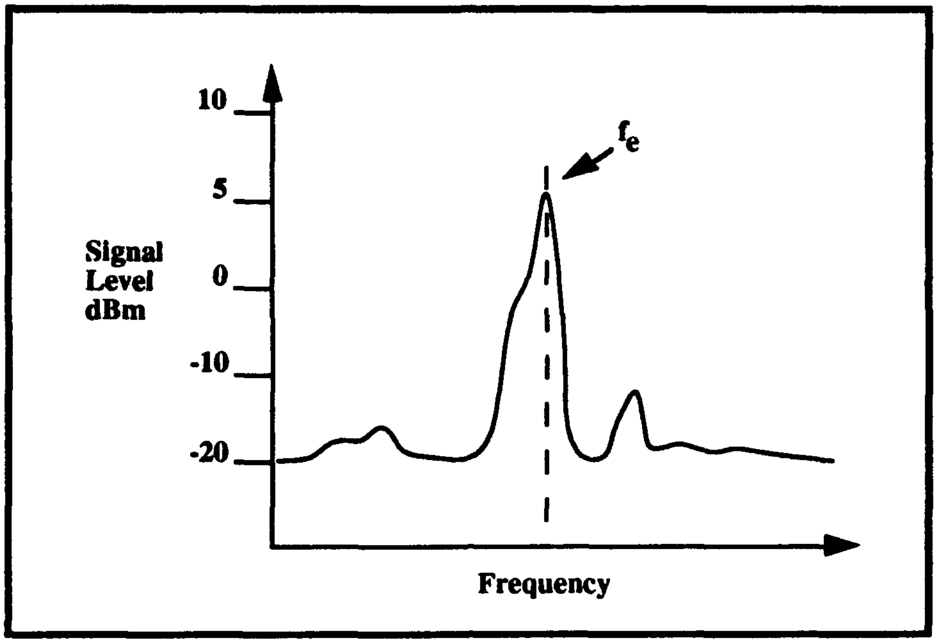


Figure 6-3. SCAL Noise-Plus-Signal Level

Were the local transmitters not active, the actual SCAL signal levels would appear as indicated in Figure 6-4.

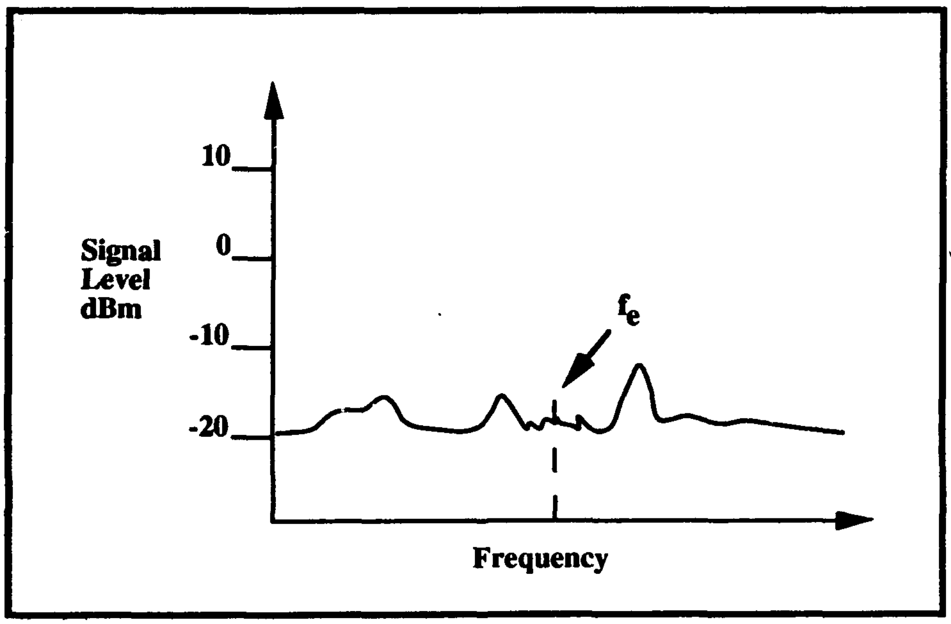


Figure 6-4. SCAL Signals Without Local Transmitter

While performing the aircraft irradiation, the actual signal levels would be similar to that in Figure 6-4 with differences resulting from aircraft attenuation and resonances. A typical graph may appear as indicated in Figure 6-5.

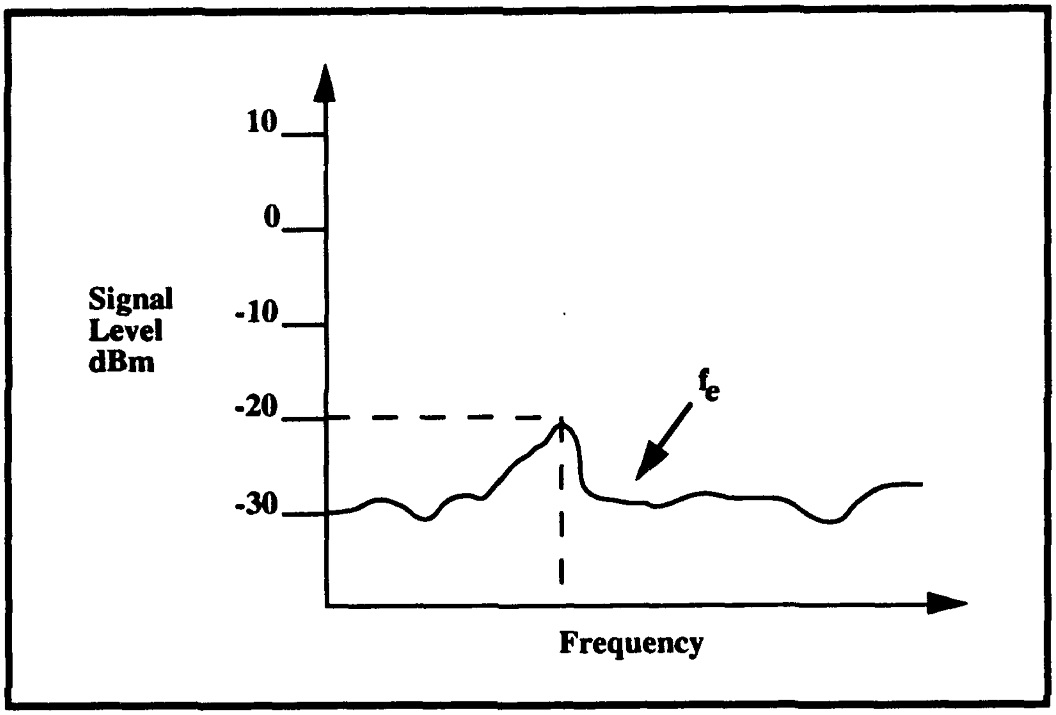


Figure 6-5. Onboard Signal Levels

Aircraft attenuation is calculated by:

Attenuation = SCAL - E-Field (irradiated)

If the SCAL level of 5 dB had a corresponding level of -20 dB, the calculated attenuation level would be 25 dB. However, the 25 dB is incorrect as the local emitter was not active.

6.5.2 Ambient Radio Frequency Environment Changes Resolution

This problem could be addressed in several ways. The first, and perhaps the most accurate, way would be to continuously monitor the ambient E-Field levels and simultaneously compare the levels to those obtained during SCAL. In the event of a significant difference (~3 dB), repeat site calibration.

Another approach would be to address this problem during data analysis by presenting the original SCAL data in conjunction with aircraft attenuation. With this approach, the reader, when unreasonable attenuation levels are encountered, can correlate back to the original SCAL data and account for the attenuation levels.

While the first approach provides the best technical solution, it is costly. If SCAL measurement were repeated, it would be quite time consuming. To apply this approach would require an additional receive node, which would entail considerable expense.

Due to fiscal constraints, the second approach was adopted for the S-76 tests.

6.6 Oversweep Versus Synchronized Sweep

For the S-76 HIRF test, an oversweep approach was used to obtain the E-Field and cable current data. That is, a signal source (either a tracking or sweep generator depending on the frequency) was set to sweep slowly while the receive spectrum analyzers were set to scan quickly (at least 1/10th of the source sweep rate). When the receive spectrum analyzer frequency matched, within its resolution bandwidth, the sources frequency, a point on the receive wave form was recorded. This approach required multiple time consuming scans to obtain an adequate wave form on the spectrum analyzers. In some cases, an adequate wave form could not be acquired.

An alternative to the oversweeping would have been a synchronized sweep approach. When applying a synchronized sweep technique, the source and receiver are simultaneously triggered and sweep at exactly the same rate. Applying this approach requires only one source and receiver sweep per band greatly reducing the overall test time and increasing the data quality.

6.6.1 Oversweep Versus Synchronized Sweep Assessment

There are several options to implementing a synchronized sweep approach. In the case of the S-76 HIRF test, two approaches were investigated.

The first approach involved using the transmit and receive equipment configurations previously discussed in this report. During the investigation, the source and receive equipment were set to identical sweep rates and simultaneously triggered. While appearing technically sound, inconsistent results were experienced. In some cases, this synchronized sweep approach performed completely as expected. However, in most cases, the source and receive equipment would drift out of synchronization resulting in no receive signal. Through discussions with the equipment manufacturers, the source of the problem was identified as internal variations in the source and receiver sweep rates. These variations, depicted in Figures 6-6 through 6-9, resulted in a condition where

- $f_s(t_o) = f_r(t_o)$; however,
- $f_s(t_o + \Delta t) \neq f_r(t_o + \Delta t)$

where

- $f_s(t_o)$ = the frequency of the source when triggered
- $f_r(t_o)$ = the frequency of the receiver when triggered
- $f_s(t_o + \Delta t)$ = the frequency of the source at t_o plus an additional time increment Δt.
- $f_r(t_o + \Delta t)$ = the frequency of the receiver at t_o plus an additional time increment Δt.

Thus, this approach was not used during the S-76 ground tests.

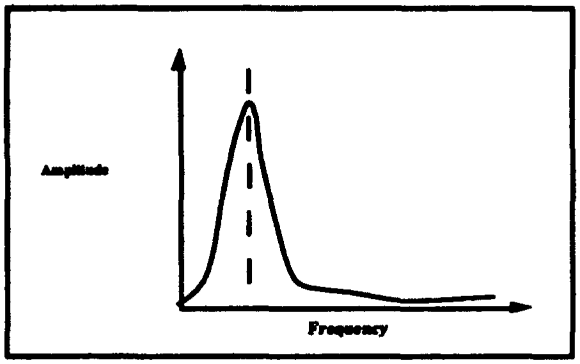


Figure 6-6. Source Signal at Time $(t_0) = 0$

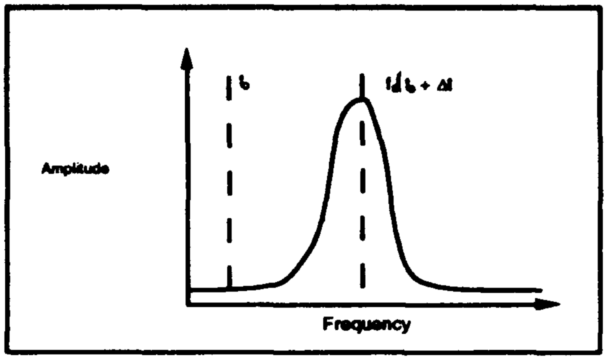


Figure 6-8. Source Signal at Time $t_0 + \Delta t$

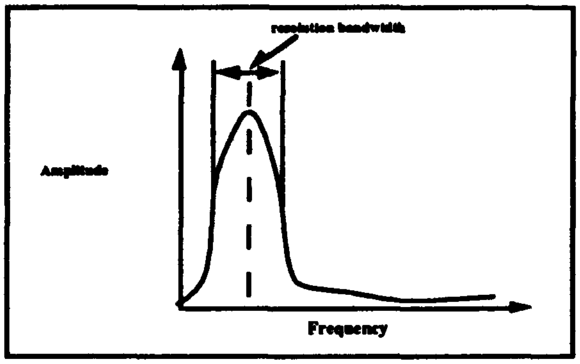


Figure 6-7. Receive Signal at $t = 0$

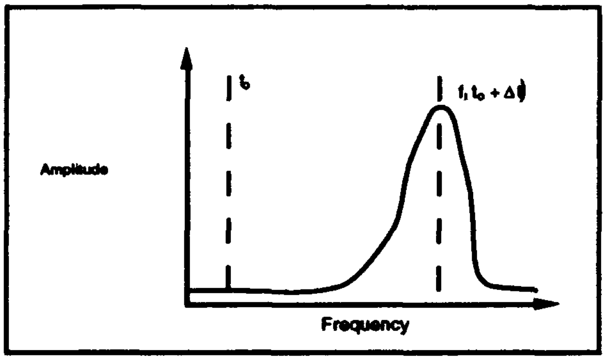


Figure 6-9. Receive Signal at Time $t_0 + \Delta t$

The second approach investigated entailed replacing the source and receive equipment with a network analyzer. With this approach, a single component would function as both the signal source and receiver eliminating the sweep rate drift problem previously discussed. While this approach was not actually tested, two major shortfalls were identified. The first and most significant problem was the availability and cost of a network analyzer usable over the frequency range of 10 kHz to 18 GHz. The second problem, as depicted in Figure 6-10, resulted from limitations of existing fiber optic converters.

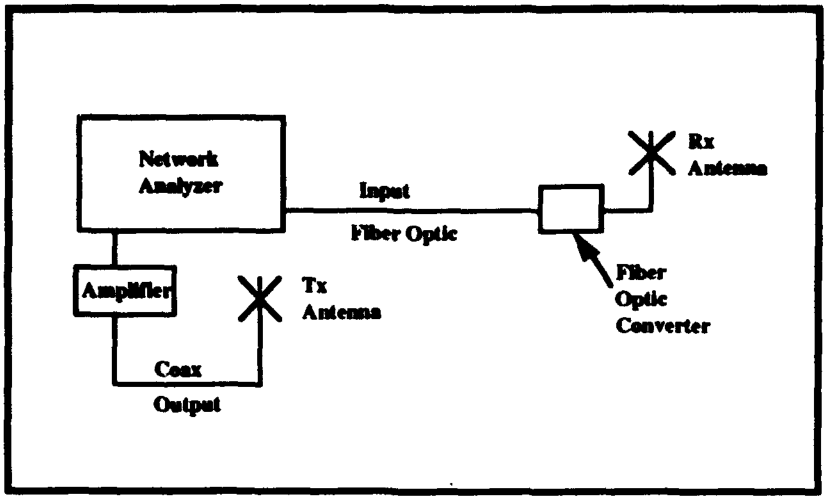


Figure 6-10. Network Analyzer Synchronized Sweep Configuration

As is standard practice when conducting HIRF tests, it is not acceptable to utilize metallic cables when connecting the transmit and receive locations. However, when utilizing a network analyzer, the signal source and receiver must reside in a single location. Regardless of the location, this configuration requires the conversion of analog signals to light over the frequency range of 10 kHz to 18 GHz. Although not exhaustive, our market survey indicated no availability of fiber optic converters above 1.8 GHz.

6.6.2 Oversweep Versus Synchronized Sweep Resolution

After evaluating the technical benefits and limitation of the above options, the decision was made to perform the S-76 HIRF test using the oversweep approach.

7. SUMMARY

The objectives of the S-76 HIRF Test Project: evaluation HIRF test practicality, HIRF effect on rotorcraft, and the threat environment were met. The following sections, provide a summary of the results and conclusions associated with the S-76 HIRF Test Project.

7.1 HIRF Test Practicality

The issue of HIRF test practicality has been raised by aircraft manufacturers, representatives of the FAA, and technical advisors to the SAE AE4R Committee. As a result of conducting the S-76 HIRF Test Project, much insight has been gained into the practicality (and feasibility) of conducting HIRF test in a technically sound and cost effective manner.

7.1.1 HIRF Test Practicality Summary Of Results

Many technical issues were encountered during the conductance of the S-76 HIRF Test Project. These issues indicate many imperfections exist in the conductance of aircraft level HIRF tests. For example, changes in the ambient RF environment during HIRF tests can have a significant impact on the results. While the technology exists to eliminate this imperfection, the cost and schedule impacts make the solution fiscally impractical. In the case of applying a synchronized sweep with a single source and receive clock, technological deficiencies in fiber optic converters prevent the necessary digital to analog conversions at frequencies above approximately 1.8 GHz.

From a cost perspective, utilization of state-of-the-art automated data acquisition and processing systems can significantly reduce the cost of conducting aircraft level HIRF tests. For example, previous HIRF tests conducted on a commercial wide body aircraft required a test crew of approximately 15 personnel. Utilization of an advanced automated data acquisition and processing system reduced the test crew requirements to 3 personnel.

7.1.2 HIRF Test Practicality Conclusions

As a result of the S-76 and other HIRF tests, it is apparent that an ideal, within an acceptable cost range, test methodology does not exist at this time. This assessment is based on technical issues including (but not limited to):

- Locating an ideal test environment large enough to accommodate all types of aircraft
- Ensuring no ambient electromagnetic field changes occur
- Achieving adequate transmit power levels over the entire 10 kHz-18 GHz frequency range
- Ensuring accuracy and validity of antenna factors in relatively small areas
- Others

However, it is possible to conduct HIRF tests in a manner which minimize technical risk and, depending on the complexity of the test, within a $150-500 K price range.

7.2 HIRF Effects On Rotorcraft

The issue of HIRF effects on rotorcraft has raised many concerns. These concerns stem from the facts that commercial rotorcraft designs require larger window areas and typically include the use of more composite materials which provide less protection against the effects of E-Fields. The concerns are further compounded by a rotocraft's typical flight characteristics (e.g., lower altitudes, hovering, etc.) which differ significantly from those of fixed wing aircraft.

7.2.1 HIRF Effects On Rotorcraft Summary Of Results

The ground tests have indicated the S-76, and perhaps most rotorcraft, are excessively susceptible to the effects of HIRF. While some extreme attenuation levels were in excess of 40 dB the average attenuation levels were on the order of 0 to 10 dB. These levels are significantly lower than those measured for commercial fixed wing aircraft with average levels ranging from 20 to 40 dB of attenuation.

As indicated in Section 4 of this report, the cable currents (when extrapolated to full threat) were above the test levels established in DO-160C. Specifically, the levels above DO-160C were experienced over the frequency range of 10 kHz to 30 MHz and 350 MHz to 1 GHz indicating higher susceptibility with regard to induced cable currents.

7.2.2 HIRF Effects On Rotorcraft Conclusions

As a result of the S-76 HIRF ground and in-flight tests, it appears that rotorcraft are inherently more susceptible to the effects of HIRF. The decrease in attenuation levels and increase in measured induced cable currents lead to the conclusion that special test criteria should be established for commercial rotorcraft.

7.3 Threat Environment Evaluation

The S-76 in-flight tests were conducted to evaluate the severity of real word emitters on aircraft while in flight. While the S-76 in-flight tests only evaluated a small sample of the actual real world emitters, the sample addresses a reasonably wide range of frequencies, power levels, and emitter types (i.e., CW and pulsed).

7.3.1 Threat Environment Evaluation Summary Of Results

Results of the S-76 tests have certainly added credibility to the existence of HIRF as a flight safety hazard. In the evaluation of the "real world" emitters, the flight tests have shown repeatable instances where exposure to "real world" HIRF emitters resulted in instrumentation disruptions.

Specifically, disruptions to the S-76's fuel flow indicator and landing gear down lights during the OTHB flight tests indicated susceptibility in the 10 to 30 MHz range. It should be noted however that no disruptions were experienced when the S-76 was exposed to high powered pulsed emitters.

7.3.2 Threat Environment Evaluation Conclusions

Since the instrument disruptions occurred only during exposure to CW emitters, it is apparent that the impact of exposure to pulsed emitters is less severe than anticipated. It should however be recognized that if the emitter frequency or pulse rate had corresponded to the digital data bus rate of the onboard processor controlled instruments the likelihood of a disruption would have been much greater.

APPENDIX A

Mechanical Characteristics

UTIFLEX Type	130	161	161S
Inner conductor diameter	.043"	.0551"	19 X .0113"
Inner conductor material	SPC	SPC	SPC
Dielectric material	LD-PTFE	LD-PTFE	LD-PTFE
Inner shield material	SPC	SPC	SPC
Outer shield material	SPC	SPC	SPC
Jacket outer diameter	.175"	.215"	.215"
Jacket material	FEP	FEP	FEP
Weight	.03 lb/ft	.05 lb/ft	.05 lb/ft
Crush strength	550 lb/ft	550 lb/ft	550 lb/ft
Min. bend radius—static	½"	⅝"	⅝"
Min. bend radius—dynamic	¾"	1"	1"
Dynamic bend endurance	5000 cycles	5000 cycles	5000 cycles

Electrical Characteristics

UTIFLEX Type	130	161	161S
Frequency range	DC-33	DC-27	DC-27
SWR	See Connector Selection Guide page 11.		
Velocity of Propagation	77%	77%	77%
Impedance	50 ± 1 Ohms	50 ± 1 Ohms	50 ± 1 Ohms
Capacitance	26.2 pF/ft	26.2 pF/ft	26.2 pF/ft
Insulation resistance	3.3 X 10^8 MΩ/ft	3.3 X 10^8 MΩ/ft	3.3 X 10^8 MΩ/ft
Isolation	-100 db @ 1GHz	-100 db @ 1GHz	-100 db @ 1GHz
Delay	1.3 ns/ft	1.3 ns/ft	1.3 ns/ft
Attenuation (max) F in GHz	$10\sqrt{F} + 0.7F$ db/100 ft	$8\sqrt{F} + 0.7F$ db/100 ft	$9.6\sqrt{F} + F$ db/100 ft
Insertion loss stability	± 0.1 db @ 18 GHz	± 0.1 db @ 18 GHz	± 0.1 db @ 18 GHz
Breakdown voltage	2500	5000	5000
Power rating	See Figure 4 on page 8.		
Phase stability			
Temperature	See Figure 5 on page 8.		
Flexure	See Figure 6 on page 8.		

ANTENNA CALIBRATION
3 METER SPACING
ICOM MODEL AH-7000
SERIAL NUMBER: 1725
MARCH 14, 1991

ANTENNA FACTORS (dB)
VERTICAL WAVE CALIBRATION

ANTENNA CONFIGURATION

FREQ (MHz)	ALL ELEMENTS	RADIALS AND SKIRTS ONLY	RADIALS ONLY
20	18.9	18.9	18.9
30	25.8	28.8	17.8
40	17.2	29.2	21.2
50	7.9	18.9	19.9
60	22.4	18.4	18.4
70	28.7	15.7	21.7
80	16.4	13.4	23.4
90	13.9	10.9	33.9
100	12.0	10.0	20.0
110	11.6	11.6	15.6
120	13.5	13.5	18.5
130	14.3	14.3	23.3
140	14.5	14.5	22.5
150	14.7	14.7	20.7
160	14.7	14.7	22.7
170	17.6	14.6	22.6
180	18.3	14.3	21.3
190	16.4	14.4	21.4
200	20.1	14.1	22.1
210	20.9	18.9	23.9
220	19.8	18.8	23.8
230	20.5	20.5	23.5
240	22.5	22.4	24.4
250	21.6	21.6	24.6
260	22.1	23.1	25.1
270	28.7	28.7	28.7
280	29.3	27.3	25.3
290	19.4	19.4	28.4
300	28.1	28.1	25.1

CONTINUED ON FOLLOWING PAGE

ANTENNA FACTOR TO BE ADDED TO RECEIVER METER READING IN dBuV TO CONVERT TO FIELD INTENSITY IN dBuV/METER.

ANTENNA CALIBRATION
3 METER SPACING
ICOM MODEL AH-7000
SERIAL NUMBER: 1725
MARCH 14, 1981

ANTENNA FACTORS (dB)
HORIZONTAL WAVE CALIBRATION

ANTENNA CONFIGURATION

FREQ (MHz)	ALL ELEMENTS	RADIALS AND SKIRTS ONLY	RADIALS ONLY
20	18.9	25.9	18.9
30	27.8	27.8	23.8
40	29.2	38.2	30.2
50	18.9	33.9	32.9
60	38.4	33.4	38.4
70	44.7	38.7	38.7
80	40.4	38.4	48.4
90	38.9	38.9	38.9
100	38.0	50.0	38.0
110	33.6	38.6	35.6
120	43.5	40.5	35.5
130	39.3	51.3	38.3
140	42.5	39.5	34.5
150	42.7	37.7	36.7
160	38.7	48.7	39.7
170	32.6	38.6	35.6
180	31.3	38.3	33.3
190	30.4	34.4	34.4
200	29.1	28.1	29.1
210	25.9	28.9	30.9
220	25.8	28.8	33.8
230	27.5	28.5	33.5
240	30.4	31.4	39.4
250	38.6	35.6	43.6
260	37.1	37.1	49.1
270	41.7	42.7	48.7
280	45.3	48.3	49.3
290	41.4	42.4	49.4
300	43.1	43.1	53.1

CONTINUED ON FOLLOWING PAGE

ANTENNA FACTOR TO BE ADDED TO RECEIVER METER READING IN dBuV TO CONVERT TO FIELD INTENSITY IN dBuV/METER

ANTENNA CALIBRATION
3 METER SPACING
ICOM MODEL AH-7000
SERIAL NUMBER: 1725
MARCH 14, 1981

ANTENNA FACTORS (dB)
VERTICAL WAVE CALIBRATION

ANTENNA CONFIGURATION

FREQ (MHz)	ALL ELEMENTS	RADIALS AND SKIRTS ONLY	RADIALS ONLY
325	24.3	24.3	23.3
350	25.8	26.8	37.8
375	28.4	25.4	38.4
400	27.0	27.0	38.0
425	28.8	28.8	35.8
450	25.5	25.5	32.5
475	38.0	29.0	35.0
500	56.4	35.4	38.4
525	34.5	42.5	32.5
550	32.2	42.7	32.7
575	60.1	37.7	37.7
600	32.9	32.8	37.8
625	27.8	30.8	33.8
650	38.4	41.4	38.4
675	34.5	34.5	40.5
700	32.7	32.7	38.7
725	32.8	31.8	40.8
750	33.8	31.6	42.6
775	32.3	31.3	38.3
800	30.8	28.8	33.8
825	31.0	30.0	33.0
850	31.2	31.2	34.2
875	31.3	31.3	34.3
900	31.6	32.8	37.6
925	33.2	33.2	43.2
950	34.4	35.4	48.4
975	36.5	37.5	44.5
1000	41.3	43.3	44.3
1100	38.9	41.9	54.3
1200	33.6	33.9	38.6
1300	36.9	36.9	44.9

ANTENNA FACTOR TO BE ADDED TO RECEIVER METER READING IN dBuV TO CONVERT TO FIELD INTENSITY IN dBuV/METER

ANTENNA CALIBRATION
3 METER SPACING
ICOM MODEL AH-7000
SERIAL NUMBER: 1725
MARCH 14, 1991

ANTENNA FACTORS (dB)
HORIZONTAL WAVE CALIBRATION

ANTENNA CONFIGURATION

FREQ (MHz)	ALL ELEMENTS	RADIALS AND SKIRTS ONLY	RADIALS ONLY
325	54.3	48.3	38.3
350	57.9	47.9	47.9
375	58.4	53.4	43.4
400	54.0	54.0	41.0
425	53.8	51.8	41.8
450	48.5	53.5	39.5
475	64.0	51.0	36.0
500	57.4	52.4	42.4
525	53.5	48.5	40.5
550	52.7	44.7	40.7
575	52.7	52.7	43.7
600	53.8	61.8	46.8
625	43.8	60.8	50.8
650	51.4	49.4	52.4
675	56.5	54.5	49.5
700	52.7	50.7	51.7
725	47.8	52.8	54.8
750	46.6	50.6	61.6
775	56.3	51.3	56.3
800	46.8	49.6	53.6
825	56.0	53.0	52.0
850	56.2	52.2	55.2
875	47.3	49.3	54.3
900	48.6	48.6	46.6
925	57.2	59.2	42.2
950	52.4	52.4	42.4
975	52.5	52.5	44.5
1000	59.3	59.3	48.3
1100	42.9	43.9	44.9
1200	51.6	61.8	46.6
1300	47.9	47.9	42.9

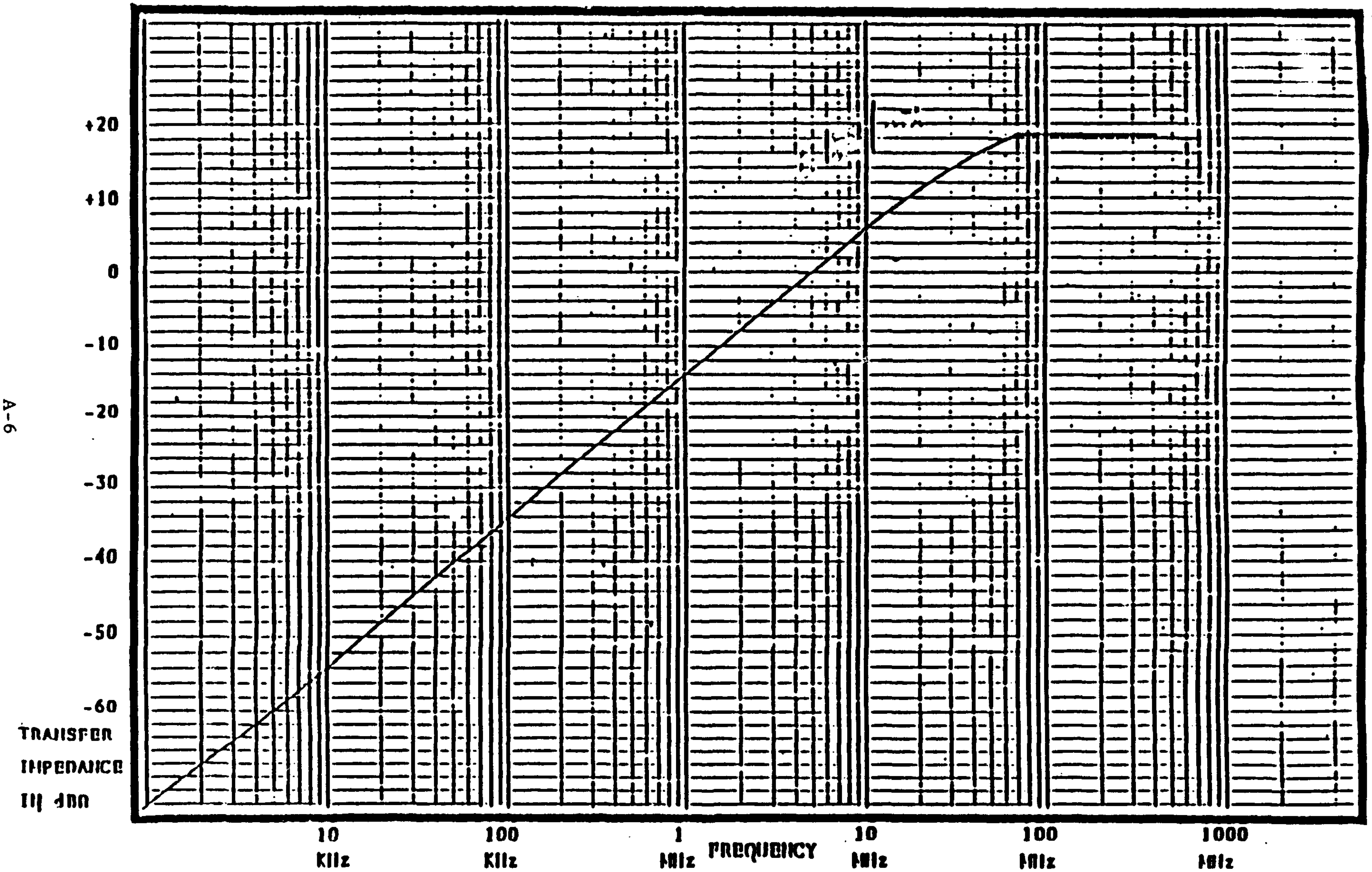
ANTENNA FACTOR TO BE ADDED TO RECEIVER METER READING IN dBuV TO CONVERT TO FIELD INTENSITY IN dBuV/METER.

A.H. Systems, Inc.
9710 Cozycroft Avenue
Chatsworth, California 91311
(818) 998-0223

TRANSFER IMPEDANCE FACTOR
RF CURRENT PROBE
MODEL BCP-200/515
SN. 127

TRANSFER IMPEDANCE CONVERSION

dBµA = dBµV - dBΩ



A.H. Systems, Inc.
9710 Cozycroft Avenue
Chatsworth, California 91311
(818) 998-0223

TRANSFER IMPEDANCE FACTOR

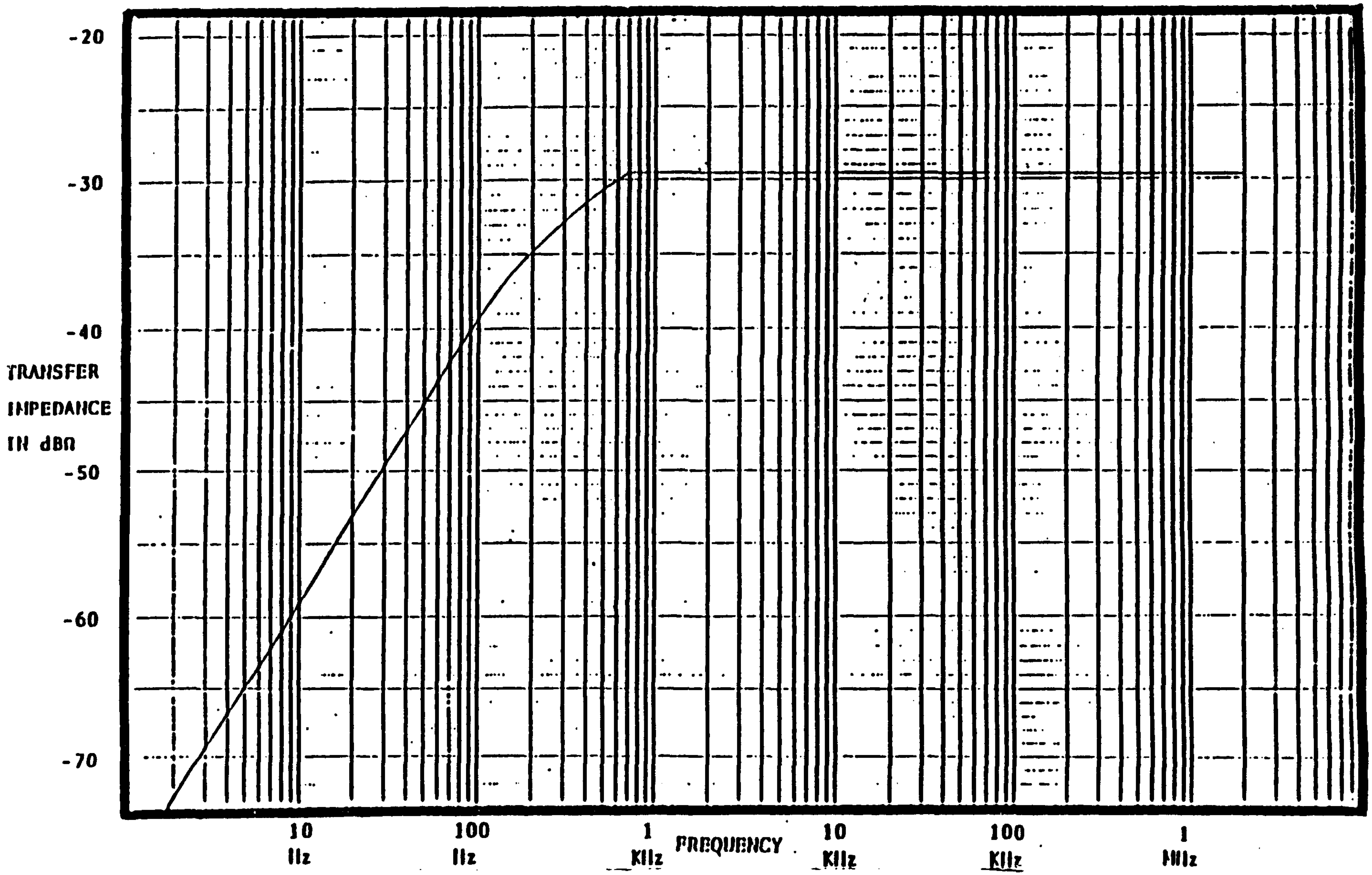
LF CURRENT PROBE

MODEL BCP-200/510

SN. 438

TRANSFER IMPEDANCE CONVERSION

dBμA = dBμV - dBΩ



A.H. SYSTEMS INC.
9710 COZYCROFT AVE.
CHATSWORTH, CA 91311
(818) 998-0223

1 METER CALIBRATION
GAIN AND ANTENNA FACTORS FOR BICONICAL ANTENNA

MODEL NUMBER : SAS-200/540
S/N : 384
DATE : 30-MAY-90

FREQUENCY (MHz)	ANTENNA FACTOR (dB)	GAIN dBi	GAIN NUMERIC
20	12.8	-16.5	.022
30	13.4	-13.6	.043
40	13.4	-11.1	.077
50	11.4	-7.17	.191
60	10.0	-4.19	.381
70	10.1	-2.95	.506
80	10.2	-1.89	.646
90	10.8	-1.46	.713
100	11.8	-1.55	.699
110	12.7	-1.62	.687
120	12.9	-1.06	.781
130	13.1	-.574	.876
140	13.1	.069	1.01
150	13.6	.168	1.03
160	13.6	.728	1.18
170	14.1	.755	1.19
180	14.3	1.05	1.27
190	15.2	.621	1.15
200	16.3	-.032	.992
210	17.5	-.809	.830
220	18.1	-1.00	.793
230	18.2	-.718	.847
240	19.0	-1.14	.767
250	18.9	-.694	.852
260	18.1	.446	1.10
270	18.3	.573	1.14
280	20.0	-.810	.829
290	24.3	-4.80	.330
300	22.3	-2.51	.560
310	24.7	-4.62	.344
320	24.6	-4.45	.358
330	25.6	-5.98	.252

ANTENNA FACTOR (1 METER SPACING) TO BE ADDED TO RECEIVER METER READING IN dBμV TO CONVERT TO FIELD INTENSITY IN dBμV/METER. CALIBRATION PER ANSI C63.5 METHODOLOGY.

1 - 12 GHz Log Periodic Antenna AHS Model SAS - 200/511

1 - 18 GHz Log Periodic Antenna AHS Model SAS - 200/518

RFI - EMI - TEMPEST - SURVEILLANCE - DIRECTION FINDING - FREQUENCY MANAGEMENT

The SAS - 200/518 Log Periodic Antenna is a linearly polarized, frequency independent, directional antenna featuring broadband 1.0 to 18.0 GHz operation. Flat impedance characteristics, well balanced patterns and low cross polarization levels are exhibited over the entire frequency band.

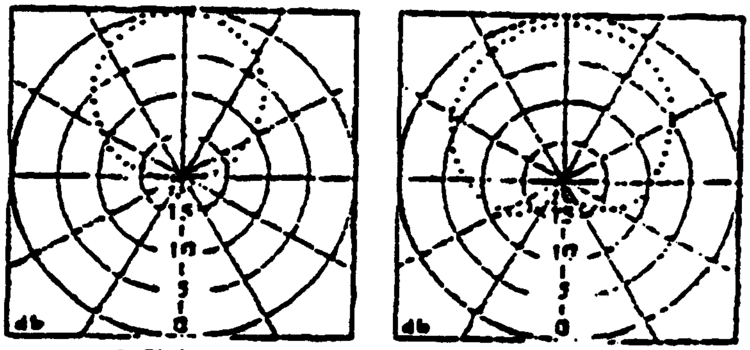
The SAS - 200/518 features excellent VSWR (typically 1.6) and a gain which ranges from 6 to 8 dB with frequency. The antenna is hermetically sealed in a low loss structural radome material and pressure isocyanate foamed. The antenna is lightweight (11 ounces) and easily adapted to various mounting configurations.

SPECIFICATIONS

Frequency Range	1.0 - 18.0 GHz			
	1 - 4 GHz	4 - 8 GHz	8 - 12.4 GHz	12.4 - 18 GHz
VSWR Typical Maximum	1.5:1 2.0:1			1.7:1 2.5:1
Gain Nominal (dBi) Minimum (dBi)	8.0 6.5			7.0 5.5
Front/Back Ratio (dB)	20			
Cross Polarization	20		15	10
E - Plane Beamwidth	65	60	55	50
H - Plane Beamwidth	105	95	90	80
Beam Squint Typical (Deg.) Maximum (Deg.)	4.0 2.0			15.0 8.0
Power Capability Peak (W) Average (W)	100 10			
Input Connector	N - Female			
Size (inches)	L = 9.7 W = 6.5 T = 0.5			
Weight (ounces)	11			
Radome Equipped	Yes			
Finish	Epoxy Paint			
Outline & Dwg No.	2135			

SAS-200/510

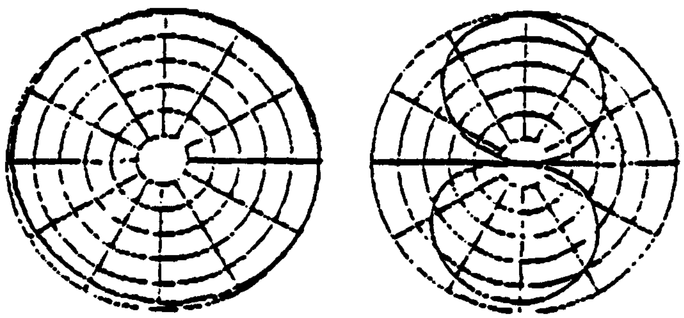
SAS-200/512



E-PLANE H-PLANE

SAS-200/530

SAS-200/542



VERTICAL POLARIZATION HORIZONTAL POLARIZATION

SAS-200/550-1 PATTERN IS OMNIDIRECTIONAL

A.H. SYSTEMS, INC
9710 COZYCROFT AVE.
CHATSWORTH, CA 91311

LOG PERIODIC ANTENNA MODEL SAS-200/512 POWER REQUIREMENTS
1000 WATTS MAXIMUM CONTINUOUS POWER

Frequency (MHz)	Power Requirements in Watts for Field Strength of					
	1 V/m	5 V/m	10 V/m	20 V/m	100 V/m	200 V/m
200	.03	.69	2.8	11.0	275	---
300	.02	.39	1.5	6.2	155	620
400	.01	.28	1.1	4.5	112	449
500	.01	.25	1.0	4.0	100	400
600	.01	.26	1.0	4.2	105	419
700	.01	.24	1.0	3.8	951	382
800	.01	.25	1.0	4.0	100	400
900	.01	.22	0.9	3.5	87	348
1000	.01	.26	1.0	4.2	105	419
1100	.01	.27	1.1	4.3	107	429
1200	.01	.31	1.2	4.9	123	492
1300	.01	.35	1.4	5.5	138	552
1400	.01	.35	1.4	5.7	141	565
1500	.01	.33	1.3	5.3	132	527
1600	.01	.26	1.0	4.2	105	419
1700	.01	.36	1.4	5.8	145	578
1800	.03	.70	2.8	11.3	282	---

A.H. SYSTEMS, INC
9710 COZYCROFT AVE.
CHATSWORTH, CA 91311

BICONICAL ANTENNA MODEL SAS-200/540 POWER REQUIREMENTS
100 WATT BALUN
1 METER SPACING
100 WATTS MAXIMUM CONTINUOUS POWER

Frequency (MHz)	Power Requirements in Watts for Field Strength of 1 V/m	5 V/m	10 V/m	20 V/m
20	1.50	37.8	----	----
30	.76	18.9	75.9	----
40	.43	10.9	43.6	----
50	.17	4.2	16.9	----
60	.09	2.2	8.9	35.6
70	.06	1.6	6.3	25.2
80	.05	1.2	4.9	19.6
90	.05	1.2	4.7	18.8
100	.05	1.2	4.7	18.8
110	.05	1.2	4.9	19.6
120	.04	1.0	4.1	16.4
130	.04	1.0	3.8	15.2
140	.03	0.8	3.3	13.2
150	.03	0.8	3.1	12.4
160	.03	0.7	2.8	11.2
170	.03	0.7	2.7	10.8
180	.03	0.7	2.6	10.4
190	.03	0.7	3.0	12.0
200	.03	0.9	3.5	14.0
210	.04	1.0	4.2	16.8
220	.04	1.0	4.2	16.8
230	.04	1.0	4.0	16.0
240	.04	1.0	4.2	16.8
250	.04	1.0	3.8	15.2
260	.03	0.7	2.9	11.6
270	.03	0.7	3.0	12.0
280	.04	1.0	4.1	16.4
290	.10	2.6	10.2	40.8
300	.06	1.4	5.8	23.2
310	.09	2.4	9.8	39.2
320	.09	2.3	9.1	36.4
330	.13	3.2	12.9	51.6

A.H. SYSTEMS, INC
9710 COZYCROFT AVE.
CHATSWORTH, CA 91311

LOG PERIODIC ANTENNA MODEL SAS-200/518 POWER REQUIREMENTS
10 WATTS MAXIMUM CONTINUOUS POWER

Frequency (GHz)	Power Requirements in Watts for Field Strength of			
	1 V/m	5 V/m	10 V/m	20 V\m
1	.01	.29	1.10	4.8
2	.01	.19	.76	3.0
3	.01	.18	.71	2.8
4	.01	.15	.60	2.4
5	.01	.14	.56	2.2
6	.01	.13	.52	2.1
7	.01	.13	.51	2.1
8	.01	.12	.49	2.0
9	.01	.13	.50	2.0
10	.01	.12	.49	2.0
11	.01	.13	.51	2.1
12	.01	.14	.55	2.2
13	.01	.14	.55	2.2
14	.01	.15	.59	2.4
15	.01	.15	.62	2.5
16	.01	.16	.63	2.5
17	.01	.17	.66	2.6
18	.01	.17	.66	2.6

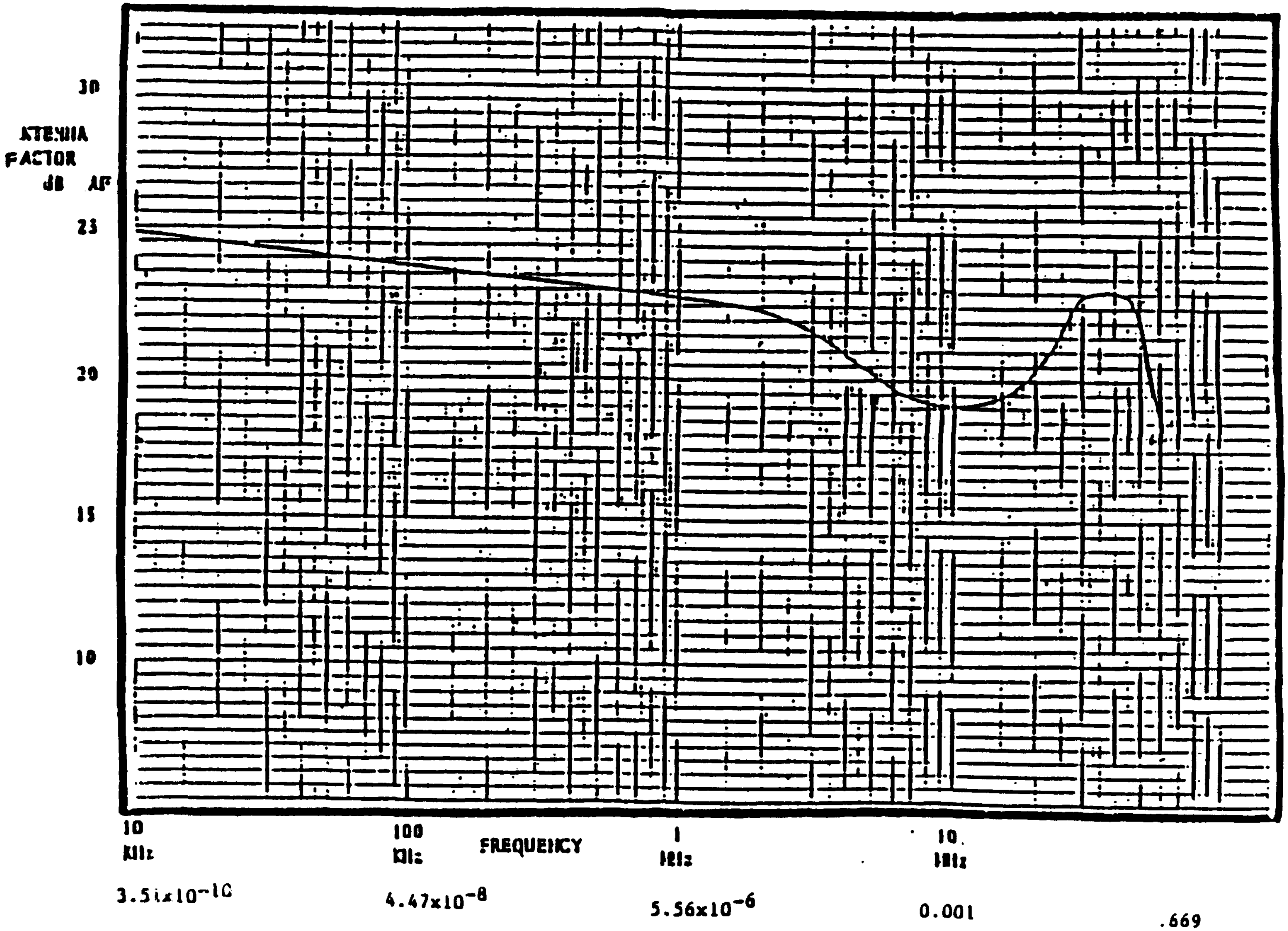
A.H. Systems, Inc.
9710 Cozycroft Avenue
Chatsworth, California 91311
(818) 998-0223

ANTENNA FACTOR-
PASSIVE MONOPOLE ANTENNA
MODEL SAS-200/551

SN.

CONVERSION OF
ANTENNA FACTORS
TO FIELD STRENGTH

dBuV + AF = dBuV/m



Active monotole response with EOD fully collapsed compared to fully extended:

Freed MHz	Response db
1	-18
20	-15
70	-18

SAS-200/540 (100 Watt Balun)

1 Meter			3 Meter		
f(Mhz)	Af(dB)	Gain(dBi)	f(Mhz)	AF(dB)	Gain (dBi)
350	35.0	-13.84	350	27.2	-6.07
375	26.9	-5.14	375	31.0	-9.27
400	26.6	-4.31	400	29.3	-6.99
425	27.8	-4.95	425	28.0	-5.27
450	31.2	-7.90	450	28.3	-4.98
475	27.2	-3.41	475	25.0	-1.24
500	26.1	-1.89	500	25.7	-1.52

3 Meter Calibration
Gain and Antenna Factors for Biconical Antenna
Model Number: SAS-200/542
SN: 606
Date: 22-Jan-89

Frequency (Mhz)	Antenna Factor (dB)	Gain dBi	Gain Numeric
20	18.8	-22.5	.005
30	15.9	-16.1	.024
40	13.2	-10.9	.081
50	8.80	-4.57	.348
60	8.40	-2.59	.550
70	8.60	-1.45	.715
80	8.20	.108	1.02
90	8.90	.431	1.10
100	9.90	.346	1.08
110	11.8	-.725	.846
120	13.4	-1.56	.698
130	14.2	-1.67	.680
140	14.4	-1.23	.753
150	14.7	-.931	.806
160	14.9	-.571	.876
170	14.7	.155	1.03
180	14.1	1.25	1.33
190	14.3	1.52	1.41
200	14.2	2.06	1.60
210	14.9	1.79	1.51
220	14.8	2.89	1.69
230	14.5	2.98	1.98
240	15.4	2.45	1.75
250	15.7	2.50	1.78
260	15.9	2.64	1.83
270	17.7	1.17	1.31
280	18.4	.789	1.19
290	18.3	1.19	1.31
300	21.1	-1.31	.739
310	23.6	-3.52	.443
320	23.1	-2.75	.530
330	24.2	-3.58	.438
350	27.2	-6.07	0.247
375	31.0	-9.27	0.118
400	29.3	-6.99	0.200
425	28.0	-5.22	0.01
450	28.3	-4.98	0.318
475	25.0	-1.24	0.752
500	25.2	-1.52	0.705

Antenna factor (3 meter spacing) to be added to receiver meter reading in dBuv to convert to field intensity in dBuV/Meter. Calibration per SAE ARP 958 methodology.

A.H. Systems, Inc.

9710 Cozycroft Avenue
Chatsworth, California 91311
(818) 998-0223

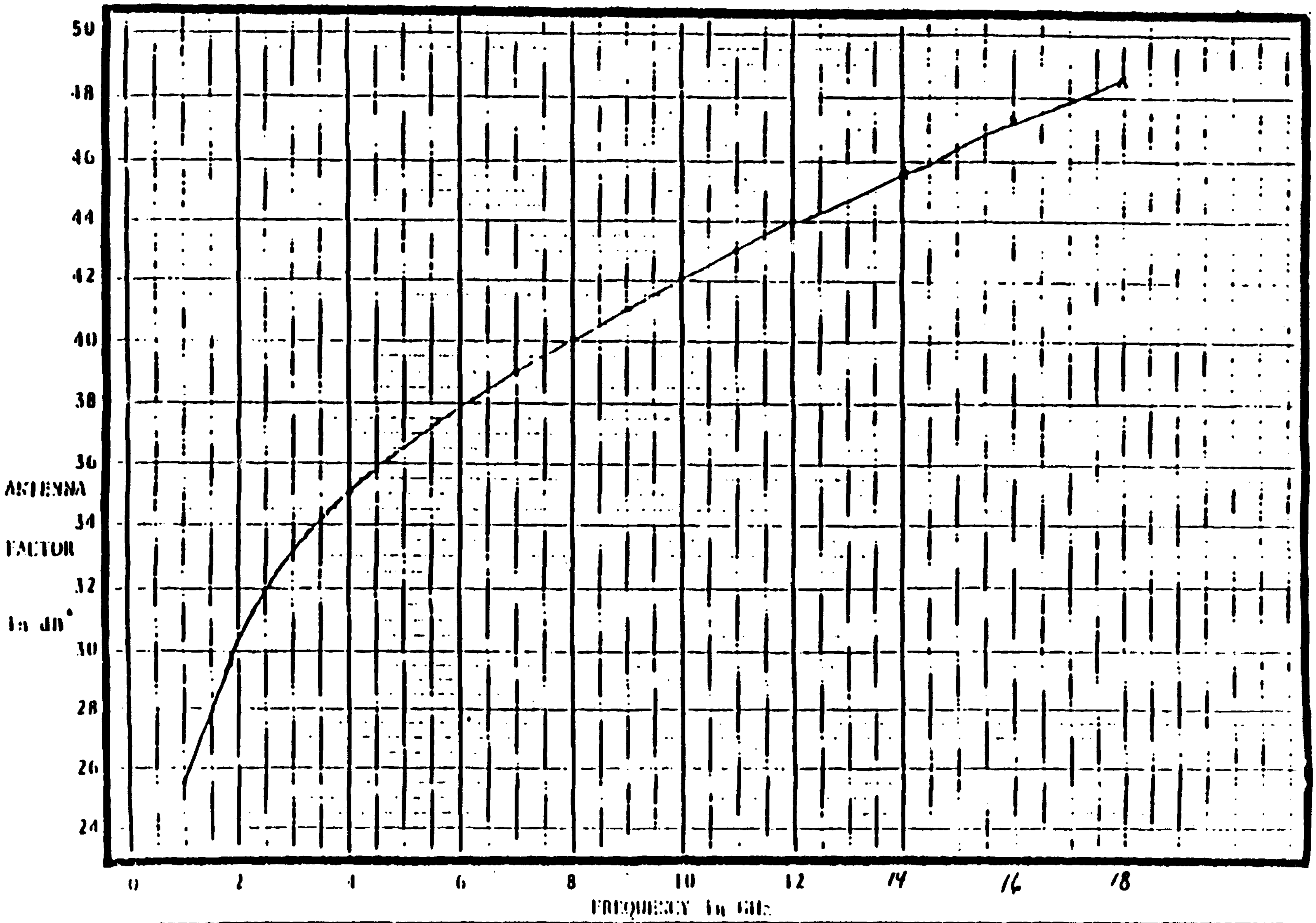
ANTENNA FACTORS - 1 METER

LOG PERIODIC ANTENNA

MODEL SAS-200/511

SN.

CONVERSION OF
ANTENNA FACTORS
TO FIELD STRENGTH
dBμV + AF* = dBμV/M



1 Meter Calibration
Gain and Antenna Factors for Log Periodic
Model Number: SAS-200/511
S/N: 202
Date: 23-Jan-89

Frequency (GHz)	Antenna Factor (dB)	Gain dB1	Gain Numeric
1.0	25.5	4.74	2.98
1.5	27.9	5.86	3.86
2.0	30.3	5.96	3.95
2.5	31.9	6.30	4.27
3.0	33.2	6.58	4.55
3.5	34.0	7.12	5.16
4.0	35.0	7.28	5.35
4.5	35.9	7.41	5.50
5.0	36.4	7.82	6.06
5.5	37.3	7.75	5.96
6.0	37.8	8.00	6.32
6.5	38.5	8.00	6.31
7.0	38.9	8.24	6.68
7.5	39.6	8.14	6.52
8.0	40.1	8.20	6.61
8.5	40.6	8.23	6.66
9.0	40.9	8.43	6.96
9.5	41.4	8.40	6.91
10.0	41.9	8.34	6.83
10.5	42.6	8.07	6.41
11.0	43.1	7.97	6.27
11.5	43.6	7.86	6.11
12.0	44.0	7.83	6.06
14.0	45.5	---	5.814
16.0	47.2	---	5.134
18.0	48.3	---	3.985

Antenna factor (1 meter spacing) to be added to receiver meter reading in dBuv to convert to field intensity in dBuV/Meter. Calibration per SAE ARP 958 methodology.

A.H. SYSTEMS INC.
3710 COZYCROFT AVE.
CHATSWORTH, CA 91311
(818) 998-0223

3 METER CALIBRATION
GAIN AND ANTENNA FACTORS FOR: LOG PERIODIC

MODEL NUMBER: SAS-200/512
S/N : 303
DATE : 23-JAN-89

FREQUENCY (MHz)	ANTENNA FACTOR (dB)	GAIN dBi	GAIN NUMERIC
200	13.8	2.46	1.76
225	16.3	.990	1.25
250	16.6	1.60	1.44
275	15.1	3.93	2.47
300	14.9	4.98	3.15
325	15.3	5.18	3.29
350	15.8	5.32	3.41
375	16.3	5.42	3.48
400	17.1	5.18	3.30
425	16.8	6.01	3.99
450	16.5	6.81	4.79
475	16.9	6.88	4.87
500	17.3	6.92	4.92
525	18.6	6.04	4.02
550	19.6	5.45	3.51
575	19.7	5.73	3.74
600	19.6	6.20	4.17
625	19.9	6.26	4.22
650	20.3	6.20	4.17
675	20.6	6.23	4.20
700	20.5	6.54	4.52
725	20.7	6.75	4.73
750	20.6	7.14	5.18
775	21.1	6.93	4.93
800	21.7	6.60	4.57
825	21.9	6.67	4.65
850	22.1	6.73	4.71
875	22.4	6.68	4.66
900	22.6	6.73	4.71
925	23.3	6.26	4.22
950	24.6	5.20	3.31
975	24.4	5.62	3.65
1000	24.3	5.94	3.93
1100	24.8	6.27	4.24
1200	25.4	6.43	4.39
1300	28.0	4.52	2.83
1400	28.4	4.76	2.99
1500	29.1	4.66	2.92
1600	29.8	4.52	2.83
1700	31.2	3.65	2.32
1800	33.0	2.35	1.71

ANTENNA FACTOR (3 METER SPACING) TO BE ADDED TO RECEIVER METER READING IN dBμV TO CONVERT TO FIELD INTENSITY IN dBμV/METER. CALIBRATION PER SAE ARP 958 METHODOLOGY.

A.H. SYSTEMS INC.
9710 COZYCROFT AVE.
CHATSWORTH, CA 91311
(818) 998-0223

3 METER CALIBRATION
GAIN AND ANTENNA FACTORS FOR LOG PERIODIC

MODEL NUMBER: SAS-200/510
S/N : 101
DATE : 23-JAN-89

FREQUENCY (MHZ)	ANTENNA FACTOR (dB)	GAIN dBi	GAIN NUMERIC
300	20.4	-.611	.868
325	15.7	4.78	3.00
350	15.1	6.02	4.00
375	15.1	6.62	4.59
400	15.4	6.88	4.88
425	15.6	7.21	5.26
450	16.1	7.21	5.26
475	16.6	7.18	5.22
500	17.8	6.42	4.39
525	18.3	6.34	4.31
550	18.3	6.25	4.22
575	18.6	6.83	4.82
600	18.3	7.30	5.38
625	19.0	7.16	5.20
650	19.6	6.90	4.90
675	20.2	6.62	4.60
700	20.7	6.44	4.41
725	20.8	6.65	4.62
750	20.7	7.04	5.06
775	20.9	7.13	5.16
800	21.4	6.90	4.90
825	21.7	6.87	4.87
850	22.2	6.62	4.60
875	22.8	6.28	4.25
900	23.3	6.02	4.00
925	23.3	5.66	3.68
950	24.0	5.80	3.80
975	24.2	5.82	3.82
1000	24.1	6.14	4.11
1100	25.3	5.77	3.77
1200	26.1	5.73	3.74
1300	26.7	5.82	3.82
1400	28.4	4.76	2.99
1500	30.2	3.56	2.27
1600	29.8	4.52	2.83
1700	30.3	4.55	2.85
1800	33.1	2.23	1.67

ANTENNA FACTOR (3 METER SPACING) TO BE ADDED TO RECEIVER METER READING IN dBuV TO CONVERT TO FIELD INTENSITY IN dBuV/METER. CALIBRATION PER SAE ARP 958 METHODOLOGY.

A.H. Systems, Inc.

9710 Cozycroft Avenue
Chatsworth, California 91311
(818) 998-0223

ANTENNA FACTORS - 1 METER

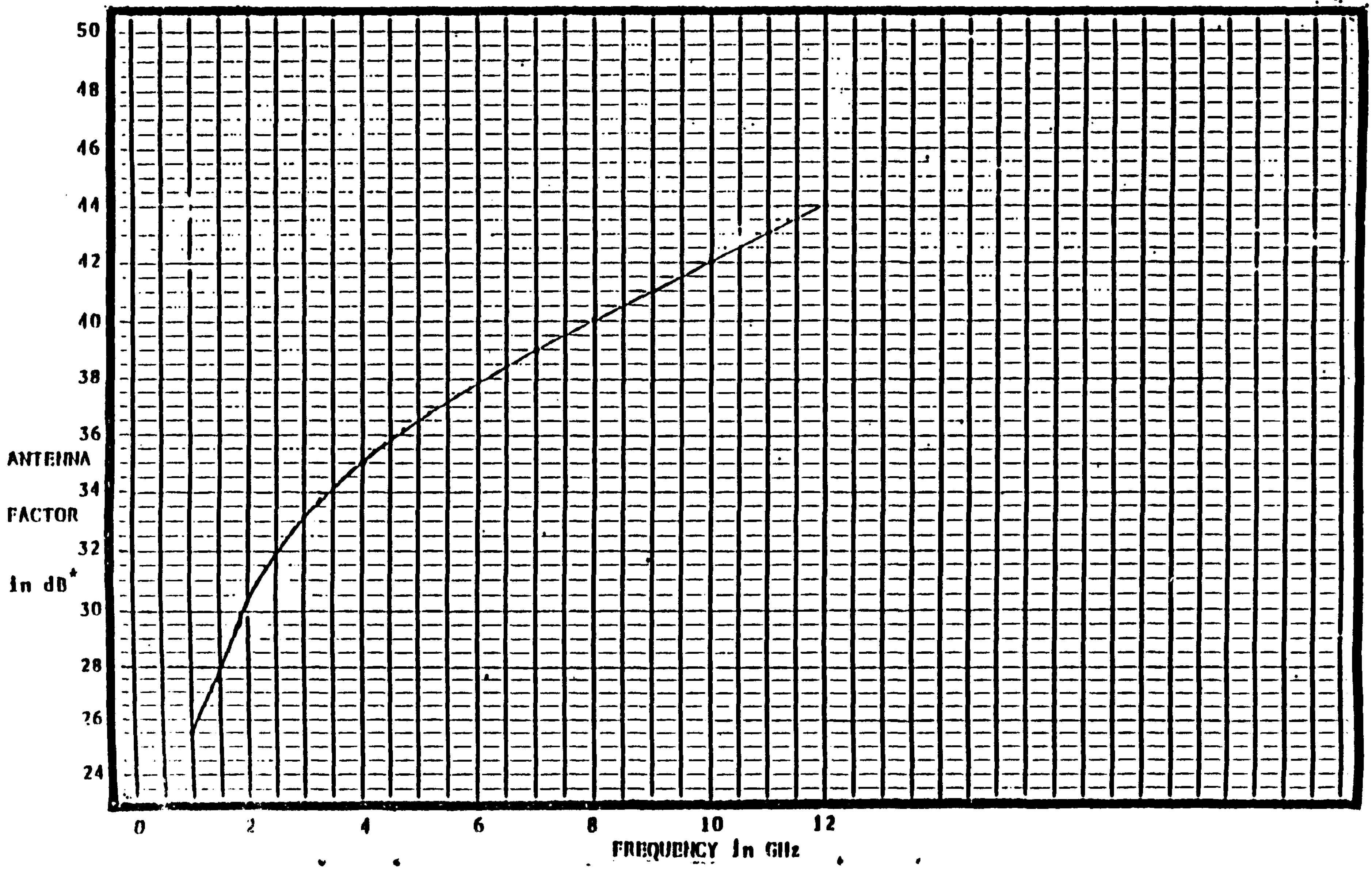
LOG PERIODIC ANTENNA

MODEL SAS-200/511

SN. 185

CONVERSION OF ANTENNA FACTORS TO FIELD STRENGTH

dBμV + AF* = dBμV/M



A.H. SYSTEMS INC.
9710 COZYCROFT AVE.
CHATSWORTH, CA 91311
(818) 998-0223

1 METER CALIBRATION
GAIN AND ANTENNA FACTORS FOR LOG PERIODIC

MODEL NUMBER: SAS-200/511
S/N : 185
DATE : 30-MAY-90

FREQUENCY (GHz)	ANTENNA FACTOR (dB)	GAIN dBi	GAIN NUMERIC
1.0	25.5	4.74	2.98
1.5	27.8	5.96	3.95
2.0	30.4	5.86	3.86
2.5	31.8	6.40	4.37
3.0	33.0	6.78	4.77
3.5	34.2	6.92	4.92
4.0	35.0	7.28	5.35
4.5	35.7	7.61	5.76
5.0	36.6	7.62	5.78
5.5	37.2	7.85	6.10
6.0	37.7	8.10	6.47
6.5	38.3	8.20	6.61
7.0	39.1	8.04	6.38
7.5	39.5	8.14	6.52
8.0	40.1	8.20	6.61
8.5	40.5	8.33	6.81
9.0	40.9	8.43	6.96
9.5	41.4	8.40	6.91
10.0	41.9	8.34	6.83
10.5	42.5	8.17	6.56
11.0	42.9	8.17	6.56
11.5	43.5	7.96	6.25
12.0	43.9	7.93	6.20

ANTENNA FACTOR (1 METER SPACING) TO BE ADDED TO RECEIVER METER READING IN dBuV TO CONVERT TO FIELD INTENSITY IN dBuV/METER. CALIBRATION PER ANSI C63.5 METHODOLOGY.

AFE.SML ==> AFE.SML 7-11-90 10:48a

0.0	-4.0
0.01	-4.0
0.10	-4.0
1.00	-4.0
10.0	-4.0
20.0	-4.0
30.0	-4.0
40.0	-3.8
50.0	-3.0
60.0	-2.2
70.0	-1.0
80.0	0.0
90.0	1.0
99.9	2.0
100.0	31.0
120.0	33.0
140.0	31.0
160.0	30.0
180.0	29.0
200.0	26.0
220.0	25.0
240.0	24.0
260.0	24.0
280.0	26.0
300.0	26.0
350.0	27.0
400.0	26.0
450.0	26.0
500.0	27.0
550.0	30.0
600.0	30.0
650.0	29.0
700.0	31.0
750.0	32.0
800.0	33.0
850.0	33.0
900.0	36.0
950.0	39.0
999.0	40.0
1000.0	34.2
1100.0	34.4
1200.0	34.6
1300.0	35.0
1400.0	35.4
1500.0	35.8
1600.0	36.0
1699.0	36.4
1700.0	36.8
1800.0	37.0
1900.0	37.8
1990.0	38.8
2000.0	39.2
2200.0	36.6
2400.0	40.3
2600.0	38.4
2800.0	41.4
3000.0	38.0
3250.0	39.8
3500.0	38.8
3750.0	40.7
4000.0	38.8
4100.0	40.0
4250.0	39.8
4500.0	41.5
4800.0	39.9
5200.0	41.4
5900.0	41.4
6200.0	42.5
6500.0	41.5
7000.0	42.1
7400.0	44.0
7800.0	42.9
8000.0	43.6
8400.0	43.5
8800.0	45.0
9100.0	44.2
9750.0	46.5
10000.	45.7
10350.	45.5
11200.	48.7
11600.	47.5
12300.	49.6
13000.	48.5
13600.	50.9
14200.	49.5
15000.	51.6
15500.	50.4
16000.	52.3
16800.	51.9
18000.	53.8
20000.	55.2
99999.	55.2

A.H. Systems, Inc.

9710 Cozycroft Avenue
Chatsworth, California 91311
(818) 998-0223

ANTENNA FACTOR

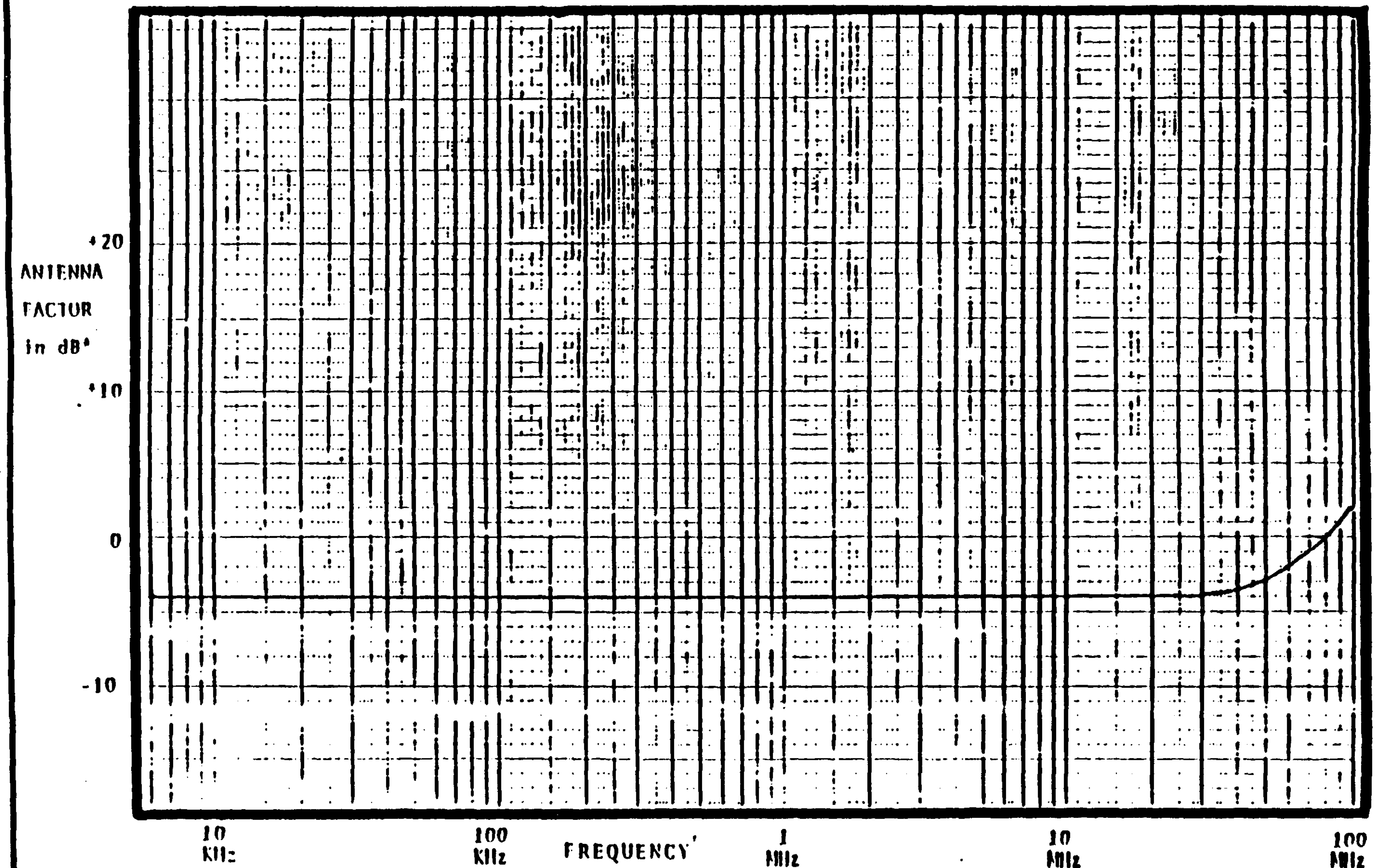
BROADBAND ACTIVE MONOPOLE ANTENNA

MODEL SAS-200/550-1

SN. 531

CONVERSION OF ANTENNA FACTORS TO FIELD STRENGTH

dBµV + AF* = dBµV/m



☆U.S. GOVERNMENT PRINTING OFFICE: 1993 - 504-078/80186